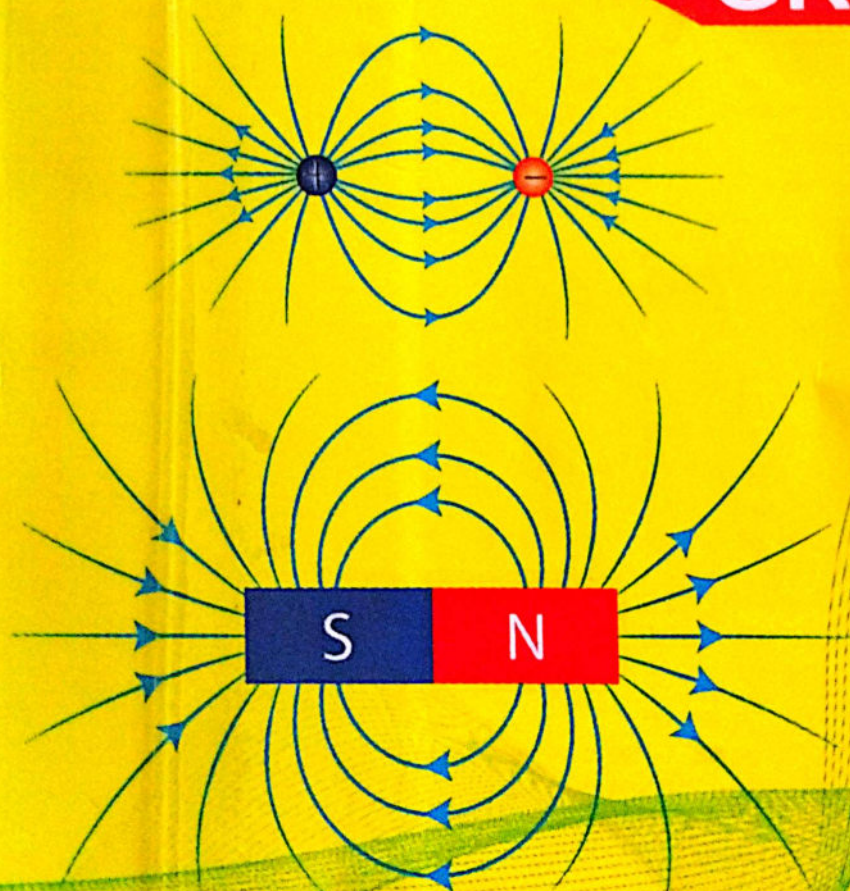


Extreme Series

PHYSICS

GRADE 9-10



**Based on Common Currently Used
National and International Curriculum**

*Extreme
Series*

2017 E.C

Abdu Yesuf (Msc)
Arebu Abdella

Extreme

PHYSICS

Grade 9 - 10



Based on Common Currently Used
National and International Curriculum

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UNIT 1

1. Physics and Human Society

1.1 What is Physics ?

1.2 Branches of Physics

1.3 Related Fields to Physics

1. Physics and Human Society

Wel Come to this fascinating unit where you will be able to define physics describe branches of physics, explain the relation of physics to other fields of study, appreciate the application of physics in the every day life and get to know the prominent contributors to the advancement of physics. Enjoy!

1.1 What is physics ?

The word physics is thought to have come from the Greek word *phusis* meaning nature. so, we can define it as a field that studies the laws of nature.

Physics : Is a branch of natural science that studies about matter, energy and their interaction

Physics, not only describes the basic principles that make the universe behave the way it does, but also helps us to understand the working manner of Cars, airplanes, rockets, radios, computers, smart phones and so much more simple and complex devices.

→ A person who studies physics is called *physicist*.

1.2 Branches of Physics

Physics do have many branches some of them are the following

→ **Mechanics :** Deals with the motion of bodies with or without considering the cause of motion that is force.

Mechanics is further divided into two as classical and quantum mechanics

→ Classical or Newtonian mechanics deals with motion and interaction between bodies.

In classical mechanics, we do not study a body that moves with a speed in an appreciable fraction of speed of light or phenomena on the atomic scale.

→ Quantum mechanics deals with behavior of molecules and particles such as electrons, protons and neutrons

- **Acoustics :** Deals with the study of sound, its transmission, production and effects.
- **Optics:** Deals with the behavior, propagation and properties of light.
- **Thermodynamics:** Deals with the concept of heat, temperature and the inter conversion of heat and other forms of energy.
- **Electromagnetism:** Deals with the electric field, magnetic field and their interaction
- **Nuclear Physics:** Deals with the structure, property and interaction of nuclei of atoms
- **Astrophysics:** Deals with the space objects and space phenomena exploration.

Illustrative Examples

1. Physics studies about

A) Living Things	C) Chemical Reaction
B) Matter and Energy	D) Politics
2. A person who studies physics is called

A) Physicist	C) Chemist
B) Physician	D) Pilote
3. The branch of physics that studies sound is

A) Optics	C) Mechanics
B) Acoustics	D) Thermodynamics
4. The branch of physics that studies light is

A) Optics	C) Mechanics
B) Acoustics	D) Thermodynamics
5. Geophysics studies the

A) Earth	B) Space	C) Ocean	D) Moon
----------	----------	----------	---------
6. Astrophysics studies the

A) Earth	B) Space	C) ocean	D) Wave
----------	----------	----------	---------
7. _____ Studies motion and interaction between bodies

- A) Thermodynamics C) Mechanics
B) Optics D) Electromagnetism
8. _____ Deals with the forces that occur between charged particles.
A) Optics C) Mechanics
B) Electromagnetism D) Acoustics
9. Heat, temperature and energy conversion studied via
A) Optics C) Acoustics
B) Thermodynamics D) Mechanics
10. The structure, property and interaction of nuclei is the concern of
A) Thermodynamics C) Mechanics
B) Electromagnetism D) Nuclear physics

Answers

1. B 4. A 7. C 10. D
2. A 5. A 8. B
3. B 6. B 9. B

1.3 Related Fields to Physics

Physics is the foundation of many disciplines. Some of them are discussed below

- **Engineering** : The design and analysis of civil, electrical, mechanical, computer, electronics and other engineering structures rely on the principles and concepts of physics.
- **Biophysics** : Makes use of the principles and methods of physics to study living things.
- **Geophysics** : Uses the principles and concepts of physics to study the Earth.
- **Medical physics** : Diagnostics and medical therapy such as x-rays, magnetic resonance imaging (MRI), ultrasound etc use principles of physics.

Conceptual Physics

11. Why is Physics considered to be the basic science ?

Explanation

Because, the concepts of physics reach up more complicated sciences.

1.4 Historical Issues and Contributors

As science and technology advanced, physics evolved from classical to modern over the centuries

Classical Physics : Evolved from the renaissance to the end of the 19th century.

Modern Physics : Starts from the beginning of the 20th century and modified many laws of classical physics.

Modern physics caused dramatic changes in technology, way of life and our view of the universe.

The most famous physicists whose thoughts and contributions revolutionized physics are given below

Physicist	Contributions
Galileo Galilei  Italian physicist and Engineer	Studied the solar - system and the universe using a telescope known as "father of physics"

Isaac Newton



English mathematician, physicist

Developing calculus, formulated laws of motion and gravitation

Greatest mathematical and physicist of all time

Micheal Faraday



English scientist

Discovered the electromagnetic induction and benzene

Studied electrolysis

James Prescott Joule



English physicist and brewer

Studied the nature of heat and its relation to mechanical energy

Marie Curie



Polish - French physicist

The first woman to win a Nobel prize for the discovery of the elements polonium and radium

Albert Einstein



German - American physicist

Best known for the general and special theory of relativity and the concept of mass - energy equivalence, $E = mc^2$

Known to be the greatest physicist of all time.

End of unit Questions

I. Give Short Answer to the following Questions

1. What is Physics ?
2. What are the branches of Physics ?
3. Name fields related to Physics
4. List some Physicist Contributed to advance Physics
5. Who Studied the rate of Energy transfer ?

i. Match items in Column "A" with those in Column "B"

A

6. Isaac Newton
7. Albert Einstein
8. Thomas Edison
9. J. J Thomson
10. Ernest Rutherford
11. James Chadwick
12. Wilhelm Conrad
13. Marie Curie
14. Joule Prescott

B

- A. Heat
- B. Electric Lamp
- C. Radium
- D. Neutron
- E. $E = mc^2$
- F. $F = ma$
- G. Electron
- H. Proton
- I. X - ray
- J. Telephone

Answer to the End of unit Questions

II. Short Answers.

1. Physics is the study of matter, energy and their interaction
2. Mechanics, optics, Acoustics, Thermodynamics, Electromagnetism
3. Biophysics, Geophysics, Engineering, medicine
4. Galilio, Newton, Einstein, Edison, Watt, Joule
5. James Watt

III. Matching Item Answers

- | | | | | |
|------|------|-------|-------|-------|
| 6. F | 8. B | 10. H | 12. I | 14. A |
| 7. E | 9. G | 11. D | 13. C | |

UNIT -2

2. Physical Quantities

2.1 Scales, Scientific Notation, Significant, Figures and Prefixes Data Measuring Scales

2.2 Measurement and Safety

2.3 Physical Quantities

2.4 Fundamental and Derived Quantities

2.5 Scalar and Vector Quantities

2.6 Vector Resolution

2.7 Addition of Vectors

2.8 Graphical Method of Vector Addition

2. Physical Quantities

We are very happy to meet you in this wonderful unit where you will get to know measuring scales, scientific notation, significant figures, prefixes and define physical quantities, differentiate basic quantities from derived quantities and distinguish scalar quantities from vector quantities. We hope, you will love it.

2.1 Scales, Scientific Notation, Significant Figures and Prefixes

What are Data Measuring Scales?

Studying natural phenomena involves quantifying events and observations. For this purpose, we use levels of measurement called *scales*.

Scale: Is a set of number or variables used to categorize, classify, compare or measure the level of something.

In physics, the most common types of data measuring scales are four. Those are, nominal, ordinal, interval and ratio scales.

Nominal Scale: Classifies or categories data without assigning number value and without ordering or ranking

For example, gender (male, female), religion (Islam, Christian), marital status (single, married), eye colour (blue, brown), subject (Physics, maths), residence area (urban, rural)...etc

→ It is a least precise method of quantification.

Ordinal Scale: Classifies data into categories that can be ordered or ranked

For example, students rank (1^{st} , 2^{nd} , 3^{rd}), body size (Small, medium, large),

judging (poor, good, excellent), grades (A, B, C)

→ Precise measurement of differences does not exist since measured values are not equally spaced.

Interval Scale: Ranks data but has no true zero value.

For example, temperature (36°C , 37°C), IQ (109, 110), SAT Score

→ Precise differences between units exist but there is no true zero.

Ratio Scale: Ranks data and has a true zero value

For example, height (1.75m, 1.78m), weight (550N, 600N), time (second, minute, hour) length (millimetre, centimeter, meter)

→ It is precise, has true zero, can be added, subtracted, divided or multiplied.

Conceptual Examples

1. Why do we say there is no precision in an ordinal scale?

Explanation

Because, when we rank observation as 1^{st} , 2^{nd} or small, large or poor, good etc... There is no fixed interval between the data. That is, the difference between 1^{st} and 2^{nd} , 2^{nd} and 3^{rd} may not be same. And, we can not tell how much small is small and how much large is large !

2. In an interval scale, there is no true zero. Why? Defend your answer.

Explanation

For example, IQ tests do not measure people who have no intelligence. And 0°C temperature does not mean no heat at all.

3. A ratio scale has a true point. Does this necessary mean value of zero can be observed for a quantity?

Explanation

No! for some quantities, a value of zero will never be observed. For example, we can never have a temperature of zero kelvin, a man of zero height, ... etc.

4. Are scales involving division of two ratio scale also themselves ratio

scales? Explain

Explanation

Yes. Ratio scales obey the four basic operations of mathematics

Illustrative Examples

5. Which scale of measurement allows the four basic operations of mathematics?

- A) Nominal B) Ordinal C) Ratio D) Interval

6. ____ Scale has the capacity to indicate the complete absence of a quantity.

- A) Nominal B) Ordinal C) Interval D) Ratio

7. Which scale of measurement is least precise?

- A) Nominal B) Ordinal C) Interval D) Ratio

8. 5 gram is one - half of 10gram, and 15gram is 3 time of 5 gram is the measure of ____ scale

- A) Nominal B) Ordinal C) Interval D) Ratio

Answers

5. C

6. D

7. A

8. D

What is Scientific Notation?

In physics, we may face numbers that are too large or too small which are inconvenient to write or to read. To avoid such difficulties scientists devised a simple method called the *scientific notation*.

Scientific Notation: Is a simple way of, writing numbers that are too small or too large using the power of ten in the form

$$d \times 10^n$$

Where: d is decimal number between 0 and 10

n is an integer exponent.

In the general form of the scientific notation, $d \times 10^n$,

- d is a decimal number with only one digit to the left of the decimal point

- $n > 0$ represents the number of times the decimal point in d moved to the right. And,
- $n < 0$ represents the number of times the decimal point in d moved to the left.

For example; $2.5 \times 10^3 = 2500\text{m}$, and

$$2.5 \times 10^{-3}\text{m} = 0.0025\text{m}$$

Illustrative Example

9. Write the following numbers using a scientific notation

- a) 300000000 m/s
b) 0.0000075m
c) 6371000m
d) 0.0002517m

Solution

- a) $3.0 \times 10^8 \text{ m/s}$
b) $7.5 \times 10^{-6} \text{ m}$
c) $6.4 \times 10^6 \text{ m}$
d) $2.5 \times 10^{-4} \text{ m}$

What are Significant Figures?

Not all digits are meaningful in a measurement

Significant Figures: Are reliable digits in a measurement

We use the following rule of thumb to determine significant figures

Rules to Determine the Number of Significant Figures

- None zero digits are considered as significant
Example: 3456m has four significant figures
- Zeros are not considered as significant
Example: 345000 has three significant figures
- Zeros between none zeroes are considered as significant
Example: 34005m has five significant figures

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- Zeroes after a decimal point are taken as significant

Example: 340.0m has four significant figures

- Zeroes indicating decimal places alone are not significant

Example: 0.0034m has two significant figures.

- Numbers in front of a power of ten are considered as significant.

Example: 2000 has one significant figure

2.0×10^4 has two significant figure

2.00×10^4 has three significant figure

Note: The numbers like 20000, 3500, 12000....etc are called *ambiguous* since they can have different number of significant figures.

Illustrative Example

10. Determine the number of significant figures for the following values.

- | | | |
|-------------|-------------------------|--------------------------|
| a) 314000m | e) 3.400kg | i) 20.0×10^3 m |
| b) 21 005kg | f) 314.201m | j) 200×10^2 m |
| c) 10.00m | g) 0.000134m | k) 30.04×10^4 m |
| d) 31.005m | h) 2.0×10^3 kg | |

Answers

- | | | | | | |
|------|------|------|------|------|------|
| a) 3 | c) 4 | e) 4 | g) 3 | i) 3 | k) 4 |
| b) 5 | d) 5 | f) 6 | h) 2 | j) 3 | |

What are Prefixes?

Scientists not only used the scientific notation to write very large or very small values, but also used symbols in front of units to replace the power of ten.

Prefix: Is a symbol or a letter used in front of units replacing the power of ten

Some of the commonly used prefixes are given below

Prefix	Symbol	Exponent	Description
Yotta	Y	10^{24}	Septillion

Unit - 2 Physical Quantities

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Zetta	Z	10^{21}	Sextillion
Ext	E	10^{18}	Quintillion
Peta	P	10^{15}	Quadrillion
Tera	T	10^{12}	Trillion
Giga	G	10^9	Billion
Mega	M	10^6	Million
Killo	K	10^3	Thousand
hecto	h	10^2	Hundred
deca	da	10^1	Ten
base	b	10^0	One
deci	d	10^{-1}	Tenth
centi	c	10^{-2}	Hundredth
milli	m	10^{-3}	Thousandth
micro	μ	10^{-6}	Millionth
nano	n	10^{-9}	Billionth
pico	p	10^{-12}	Trillionth
Femto	f	10^{-15}	Quadrillionth
Atto	a	10^{-18}	Quintillionth
Zepto	Z	10^{-21}	Sextillionth
Yocto	y	10^{-24}	Septillionth

Conceptual Example

11. Do all pre fixes exist in front of SI units? Explain

Explanation

Not all. For example, kilogram (kg) is the SI unite of mass. Here, even if kilo (K) is a prefix, gram (g) is not an SI unit. ok!

Illustrative Examples

12. Write the following values using an appropriate prefixes

- The radius of the Earth is 6,371,000m
- The diameter of hair is 0.000,0075m
- The speed of light in vacuum is 300,000,000m/s

d) The distance of the sun from the earth is 150,000,000,000m

Answers

- a) 6.4Mm b) 7.5 μ m c) 0.3G m/s d) 0.15Tm

2.2 Measurement and Safety

Our daily life is engaged in measuring things for different reasons. We say a kilo of sugar, banana, coffee, a litter of water, milk, nafta, a meter of cloth, string, cable and an hour, a day, a month and, year etc

Measurement: Is a process of comparing an unknown quantity with a known and internationally accepted standard unit of that quantity

For example, if we say 5kg of banana, it means that, the amount of banana, we are talking about is 5times large as the kilogram which is the standard unit of mass.

In a measuring process, there are three key common elements

- The quantity to be measured
- The measuring instrument
- The standard unit of measurement

For example, we have the following measurements

Physical Quantity	Measuring Instrument	Standard Unit
Time	Clock	Second
Length	Meter Tape	Meter
Mass	Balance	Kilogram

Laboratory Safety Rules

In a laboratory where experiment is done, since toxic chemicals and hazardous materials exist, students should follow safety rules so that physics laboratory can be a safe and enjoyable place for learning and discovery.

Some of the common laboratory safety rules are:

- Wear a laboratory safety goggles, shoes, cloths etc
- Avoid wearing baggy clothing, bulky jewelry, dangling bracelets, sandals.... etc

- Do not eat, drink, chew gum in the laboratory
- Never taste or smell chemicals
- Wash hands thoroughly after laboratory work
- Do not touch bare wires if not insulated
- Stand by hazard reducing materials like fire extinguisher

Illustrative Example

13. What is an SI unit? Explain

Explanation

SI unit standard for system international is a world wide accepted standard unit of measurement. As an example, the SI unit of time is second (S), the SI unit of length is meter (m) and the SI unit of temperature is kelvin (K)

2.3 What are Physical Quantities?

Quantities that can be measured directly or indirectly are known as physical quantities. The measured value of a physical quantity is described using a number and a unit.

Physical Quantity: Is anything that can be measured and expressed using number and unit

For example, if you have 3kg of banana, then the quantity measured is mass with a magnitude of 3 and a unit of kilogram.

Physical quantities are classified into two major categories as;

- Fundamental and Derived
- Scalar and Vector

So, now let's define and explain them one by one

2.4 Fundamental and Derived Quantities

Based on whether a physical quantity is measured directly or not, we classify it as fundamental or as a derived quantity.

d) The distance of the sun from the earth is 150,000,000,000m

Answers

- a) 6.4Mm b) 7.5 μ m c) 0.3G m/s d) 0.15Tm

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- Fundamental and Derived
- Scalar and Vector

So, now let's define and explain them one by one

2.4 Fundamental and Derived Quantities

Based on whether a physical quantity is measured directly or not, we classify it as fundamental or as a derived quantity.

Fundamental Physical Quantity: Is a quantity that can be measured and defined directly.

A fundamental physical quantity is also called a *basic physical quantity* and its unit is called *basic unit*.

→ A basic unit is a directly defined unit and it does not depend on other units.

The seven fundamental physical quantities and their basic units are given below

Basic Quantity	Symbol	Basic unit	Symbol
Length	ℓ	meter	m
Mass	m	kilogram	kg
Time	t	second	S
Temperature	T	kelvin	K
Electric Current	I	Ampere	A
Amount of substance	n	Mole	mol
Luminous Intensity	I_v	Candela	Cd

As an example, let's see how the quantities time, length and mass are directly defined.

Time: Is the duration between the beginning and end of an event.

The SI unit of time is the second (S)

→ Second is defined as 9192631770 times the period of vibration of cesium - 133 atom.

None SI units of time are minute (min), hour (hr), day, month and year.

The Units of Time are Related as Shown Below

1 minute	60 seconds
1 hour	60 minutes
1 day	24 hours
1 week	7 days
1 month	30 days
1 year	365.25 days

Illustrative Example

14. Express the following durations in seconds

- a) 3 hours c) $\frac{2}{5}$ hours e) 2.5 hours
b) 0.2 hours d) 45 minutes f) 30.5 minutes

15. Express the result of the following durations in seconds

- a) 2 hours + 0.3 hours
b) 3 hours + 0.4 hours + 20 minutes

Solutions

14. a) 3 hours = (3) (60) (60) = 10800 seconds

b) 0.2 hours = (0.2) (60) (60) = 720 seconds

c) $\frac{2}{5}$ hours = $\left(\frac{2}{5}\right) (60) (60) = 1440$ seconds

d) 45 minutes = (45) (60) = 2700 seconds

e) 2.5 hours = (2.5) (60) (60) = 9000 seconds

f) 30.5 minutes = (30.5) (60) = 1830 seconds

15.

a) 2 hours + 0.3 hours = (2) (60) (60) + (0.3) (60) (60) = 8280 seconds

b) 3 hours + 0.4 hours + 20 minutes
= (3) (60) (60) + (0.4) (60) (60) + (20) (60) = 13440 seconds

Length: Is the distance between two points

The SI unit of length is the meter (m)

→ Meter (m) is defined as a distance travelled by light in vacuum in a time of $\frac{1}{299792458}$ second.

None SI unit of length are millimetre (mm), centimeter (cm) and kilometer (Km)

The Units of Length are Related as Shown Below

1 centimeter	10 millimeter
1 meter	100 centimeter
1 kilometer	1000 meter

Illustrative Examples

16. If the distance between two bus stations is 500m, then what is this distance in

- a) Millimeter b) Centimeter c) Kilometer

17. Express the sum of the distance given below in meter

- a) $0.2\text{km} + 500\text{cm} + 2500\text{mm}$
 b) $\frac{1}{4}\text{ km} + 3.5\text{km} + 45000\text{mm} + 2500\text{cm}$

Solutions

16. a) $500\text{m} = (500) (100) (10) = 500,000\text{ mm}$

b) $500\text{m} = (500) (100) = 50,000\text{ cm}$

c) $500\text{m} = (500) \left(\frac{1}{1000}\right) = 0.5\text{km}$

17. a) $0.2\text{km} + 500\text{cm} + 2500\text{mm}$

$$= (0.2) (1000) + (500) \left(\frac{1}{100}\right) + 2500 \left(\frac{1}{1000}\right)$$

$$= 200 + 5 + 2.5 = 207.5\text{m}$$

b) $\frac{1}{4}\text{ km} + 3.5\text{km} + 45000\text{mm} + 2500\text{cm} =$

$$\left(\frac{1}{4}\right) (1000) + (3.5) (1000) + (45000) \left(\frac{1}{1000}\right) + 2500 \left(\frac{1}{100}\right)$$

$$= 250 + 3500 + 45 + 25 = 3820\text{m}$$

Mass: Is the amount of matter contained in a body

The SI unit of mass is the kilogram (kg)

→ Kilogram is defined as the mass of a particular platinum - iridium alloy cylinder in paris, France.

None SI unit of mass are gram (g), milligram (mg) quintal. and tonne.

The Units of Mass are Related as Shown Below

1 gram	1000 milligram
1 kilogram	1000 gram
1 quintal	100 kilogram
1 tonne	10 quintal

Illustrative Examples

18. If you buy 3 kilogram of banana, what is this amount in

- a) Gram b) Milligram c) Quintal d) Tonne

19. Express the sum of the masses given below in kilogram

a) $0.2\text{ ton} + 0.5\text{ quintal} + 5000\text{ gram}$

b) $\frac{1}{5}\text{ ton} + 2.5\text{ quintal} + 2500\text{ gram}$

Solutions

18. a) $3\text{kilogram} = (1000) = 3000\text{ gram}$

b) $3\text{kg} = (3) (1000) = 3,000,000\text{ milli gram}$

c) $3\text{kg} = (3) \left(\frac{1}{100}\right) = 0.03\text{ quintal}$

d) $3\text{kg} = (3) \left(\frac{1}{1000}\right) = 0.003\text{ tonne.}$

19. a) $0.2\text{ ton} + 0.5\text{ quintal} + 5000\text{gram}$

$$= (0.2) (1000) + (0.5) (100) + (5000) \left(\frac{1}{1000}\right)$$

$$= 255\text{kg}$$

b) $\frac{1}{5}\text{ ton} + 2.5\text{ quintal} + 2500\text{gram}$

$$= \left(\frac{1}{5}\right)(1000) + (2.5)(100) + (2500)\left(\frac{1}{1000}\right)$$

$$= 452.5\text{kg}$$

More over, physical quantities that can not be defined or measured directly are called *derived quantities*.

Derived Physical Quantity: Is a quantity that can be obtained by combining, that is dividing or multiplying two or more basic quantities.

For example, Area, Speed, density, force, pressure e.t.c are derived quantities.

→ The unit of derived quantities are called *derived units*.

Some of the derived quantities along with their units are give below:

Derived Quantity	Symbol	Formula	Unit	Symbol
Speed	v	$\frac{\text{Distance}}{\text{Time}}$	$\frac{\text{meter}}{\text{Second}}$	m/s
Density	ρ	$\frac{\text{mass}}{\text{volume}}$	$\frac{\text{kilogram}}{\text{meter cube}}$	kg/m ³
Acceleration	a	$\frac{\text{veloccity change}}{\text{Time}}$	$\frac{\text{meter}}{\text{second square}}$	m/s ²
Force	F	(Mass) (Acceleration)	Newton	IN = $\frac{1\text{kgm}}{\text{s}^2}$
Work	W	(Force) (Displacement)	Joule	1J = $\frac{1\text{kgm}^2}{\text{s}^2}$
Pressure	P	$\frac{\text{Force}}{\text{Area}}$	Pascal	1Pa = $\frac{1\text{kg}}{\text{ms}^2}$

Illustrative Examples

20. Which of the following is basic quantity?
 A) Work B) Density C) Mass D) Pressure
21. Identify the basic unit
 A) Kelvin B) Pascal C) Joule D) Newton
22. All pairs represent derived quantities, except
 A) Work, speed C) Density, volume
 B) Mass, time D) Area, speed
23. Which of the following is a derived quantity?
 A) Current B) Speed C) Length D) Temperature
24. Identify the derived unit
 A) Kelvin B) Mole C) Ampere D) Newton
25. All pairs represent basic units, Except
 A) Kelvin, kilogram C) Ampere, kelvin
 B) Ampere, Joule D) Kelvin, Candela
26. All pairs represent derive units, Except
 A) Candela, Joule C) Joule, Newton
 B) Pascale, Newton D) Tesla, Weber

Answers

20. C 22. B 24. D 26. A
 21. A 23. B 25. B

2.5 Scalar and Vector Quantities

Some physical quantities can be described by a number and a unit, that is magnitude alone, and some others are expressed using a magnitude and direction.

Scalar Quantity: Is a quantity that can completely be described by magnitude alone.

For example, time, mass, temperature, density, volume etc are scalar

Conceptual Examples

27. Why do we say that quantities such as time, mass and temperature are scalar quantities? Explain

Explanation:

Because, they do not require direction for their description. For example, it is expressive to say 3 hours, 2kg or 37°C. You do not need to say 3 hours to the east, 2kg due west or 37°C towards the south etc. ok!

28. Can we conclude that, all the fundamental quantities are also scalar quantities

Explanation

Yes. All the seven basic quantities are scalar quantities

Vector Quantity: Is a quantity that requires both magnitude and direction for its complete description

For example; displacement, velocity, acceleration, force, ... etc are vector quantities.

Conceptual Example

29. Why do we say quantities such as velocity and force are vector quantities? Explain

Explanation

Because they require direction for their complete description. For example, saying a force of 500N is acting towards north and a car is moving at 30km/h due East makes sense.

30. Can we conclude that, all the derived quantities are also vector quantities?

Explanation

No. Not all. For example, area, volume, density, speed, pressure... etc are derived quantities. But, are not vector quantities.

Illustrative Example

31. Which of the following is a vector quantity?

- A) Current B) Temperature C) Force D) Pressure

32. Which Pairs are scalars?

- A) Speed, Force C) Velocity, Force
B) Acceleration, pressure D) Density, pressure

33. All pairs are vector quantities except

- A) Speed, distance C) Acceleration, velocity
B) Velocity, force D) Force, velocity

34. Which of the following is a scalar quantity?

- A) Acceleration C) Velocity
B) Pressure D) Force

35. All pairs are scalars except

- A) Acceleration, speed C) Temperature, speed
B) Current, mass D) Density, volume

Answers

31. C 32. D 33. A 34. B 35. A

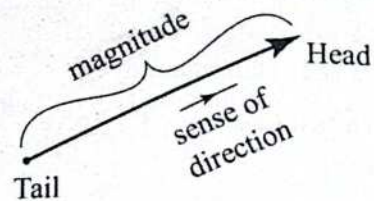
A Vector Quantity can be Represented Either Algebraically or Geometrically

→ Algebraically, a vector is represented by a bold face letter or a letter with an arrow over its head.

For example, a force vector can be represented as $\mathbf{F}$ or $\vec{F}$ and the magnitude of the vector is represented by a light face letter or a letter in the absolute value notation as F or $|F|$.

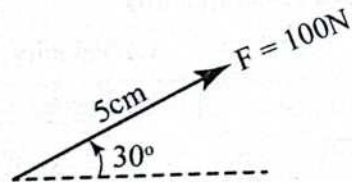
→ Geometrically, a vector is represented by an arrow that is drawn to an appropriate scale.

The initial point of the arrow is a tail and its final point is a head. If the arrow is drawn to scale, then its length represents the magnitude and its head indicates the direction of the vector as shown below



While expressing a vector geometrically, we use an appropriate scale to draw its magnitude and a protractor to determine its direction.

For example, to represent a force of 100N that is acting at an angle of 30° from the horizontal, we may let $1\text{cm} = 20\text{N}$, hence $5\text{cm} = 100\text{N}$, use a ruler and draw 5 cm at an angle of 30° from the horizontal using a protractor as shown

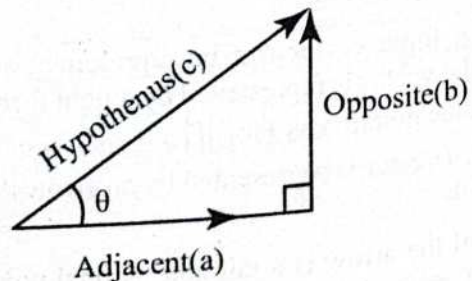


2.6 What is Vector Resolution?

A vector can be decomposed into parts, and this process is called *resolution*.

Vector Resolution: Is the process of splitting a vector into components.

To resolve a vector into horizontal or x - component and vertical or y - component, we need to use the basic trigonometric relations as defined below.



$$\sin \theta = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{b}{c} \Rightarrow b = C \sin \theta$$

$$\cos \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}} = \frac{a}{c} \Rightarrow a = C \cos \theta$$

$$\tan \theta = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{b}{a} \Rightarrow \theta = \tan^{-1} \left(\frac{b}{a} \right)$$

And, to combine the components, into one magnitude, we use Pythagora's theorem as follows;

$$c^2 = a^2 + b^2$$

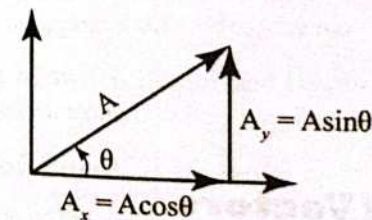
$$c = \sqrt{a^2 + b^2}$$

And, the angle that c makes from a is obtained from

$$\tan \theta = \frac{b}{a}$$

Now, suppose we want to decompose vector $\vec{A}$ into a horizontal

Component, $\vec{A}_x$ and a vertical component, $\vec{A}_y$ such that, $\vec{A} = \vec{A}_x + \vec{A}_y$



We Know;

$$\cos \theta = \frac{A_x}{A} \Rightarrow A_x = A \cos \theta$$

$$\sin \theta = \frac{A_y}{A} \Rightarrow A_y = A \sin \theta$$

Where: θ is the angle that vector A makes with the x - axis, and the magnitude of vector A is obtained by:

$A = \sqrt{A_x^2 + A_y^2}$, and its direction is;

$$\tan \theta = \frac{A_y}{A_x} \Rightarrow \theta = \tan^{-1} \left(\frac{A_y}{A_x} \right)$$

Illustrative Examples

36. An automobile moved a distance of 4000m at an angle of 37° north of east. What are the x and y components of the displacement of the automobile?
37. If a bus moved 5km due east and then 10km at 53° from the horizontal, then what is the over all displacement of the bus.

Solution

$$36. S_x = S \cos \theta = (4000) \cos (37^\circ) = (4000) (0.8) = 3200\text{m}$$

$$S_y = S \sin \theta = (4000) \sin (37^\circ) = (4000) (0.6) = 2400\text{m}$$

$$37. S_x = 5\text{km} + 10 \cos (53^\circ) = 5 + 6 = 11\text{km}$$

$$S_y = 0 + 10 \sin (53^\circ) = 0 + 8 = 8 \text{ km}$$

$$S = \sqrt{S_x^2 + S_y^2}$$

$$S = \sqrt{11^2 + 8^2}$$

$$S = 13.6 \text{ km}$$

2.7 Addition of Vectors

When we add vector quantities, we need to consider both their magnitude and their directions. And, the sum or difference of two or more vectors is called *resultant*.

Resultant Vector: Is a single vector obtained by adding two or more vectors and whose effect is the same as the individual vectors acting together.

To add scalars, we use ordinary algebra while, to add vectors we make use of vector algebra.

Conceptual Examples

38. Can we add a scalar quantity to vector quantity? Explain

Explanation

Never! For example, no quantity exists being the sum or difference of force and velocity, acceleration and displacement..... etc.

39. Can we add vectors of different kind? Explain

Explanation

No. That is not possible. For example, we get nothing if we try to add force and velocity or acceleration and displacement.

40. If we have force of 4N and 6N, Can we conclude that their result is 10N? Explain

Explanation

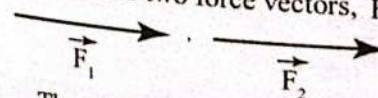
No! Depending on their directions, the resultant of a 4N and a 6N force varies from 2N to 10N. For example, when they are acting in the same direction, their resultant is 10N, when they are acting at right angle to each other, their resultant is 7.21N and when they are acting in opposite directions, the magnitude of their resultant is 2N

The resultant of two vector $\vec{A}$ and $\vec{B}$ can be denoted by $\vec{R}$, and let's consider three cases one by one

Addition of Parallel Vectors

The magnitude of the resultant of two vectors acting in the same direction is equal to the sum of the magnitude of the two vectors and its direction is in the direction of the two vectors.

That is, if we have two force vectors, $\vec{F}_1$ and $\vec{F}_2$ as shown



Then their resultant is

$$\vec{R} = \vec{F}_1 + \vec{F}_2 = \vec{R}$$

Addition of Antiparallel Vectors

The magnitude of the resultant of two vectors acting in opposite directions is the difference of the magnitude of the two vectors and its direction is in the direction of the bigger vector

That is, if we have two force vectors $\vec{F}_1$ and $\vec{F}_2$ as shown



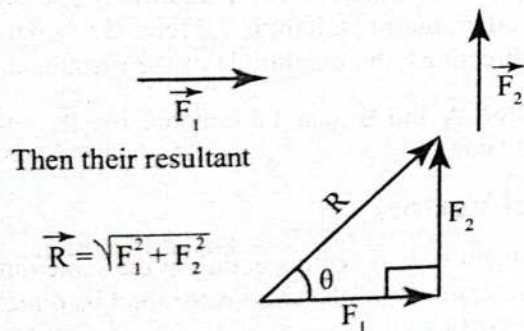
Then their resultant

$$\vec{R} = \vec{F}_1 - \vec{F}_2 = \vec{R}$$

Addition of Perpendicular Vectors

The magnitude of the resultant of two vectors acting at right angle to each other is obtained by using pythagora's theorem and its direction is determined using the basic trigonometric relations.

That is, if we have two force $\vec{F}_1$ and $\vec{F}_2$ as shown



Then their resultant

$$R = \sqrt{F_1^2 + F_2^2}$$

$$\tan \theta = \frac{F_2}{F_1} \Rightarrow \theta = \tan^{-1} \left(\frac{F_2}{F_1} \right)$$

Illustrative Example

41. Given two forces; $F_1 = 6\text{N}$ and $F_2 = 8\text{N}$. Find their resultant when

- $F_1 = 6\text{N}$, East and $F_2 = 8\text{N}$ East
- $F_1 = 6\text{N}$, East and $F_2 = 8\text{N}$ West

c) $F_1 = 6\text{N}$, East and $F_2 = 8\text{N}$ North

Solution

a) The two forces are parallel

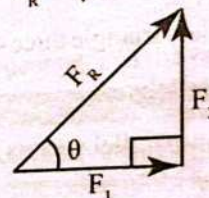
$$F_R = F_1 + F_2 = 6 + 8 = 14\text{N, East}$$

b) The two forces are anti parallel

$$F_R = F_1 - F_2 = 6 - 8 = -2\text{N, East} = 2\text{N, west}$$

c) The two forces are perpendicular

$$F_R = \sqrt{F_1^2 + F_2^2} = \sqrt{6^2 + 8^2} = \sqrt{100} = 10\text{N}$$



$$\sin \theta = \frac{F_2}{R} = \frac{8}{10} = 0.8$$

Then, using scientific calculator, $\theta = \sin^{-1}(0.8) = 53^\circ$

Hence, the resultant is 10N at 53° North of East.

- The resultant of two vectors is maximum when they are acting in the same direction or parallel, and it is minimum when they are acting in opposite directions or anti parallel

2.8 Graphical Method of Vector Addition

To add vectors graphically, we use a ruler to determine their magnitude and a protractor to determine their direction. Here under, we define the triangle law, the parallelogram law and the polygon law of vector additions. Enjoy!

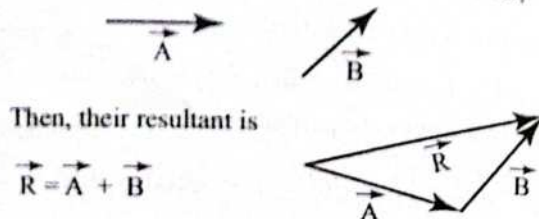
Triangle Law of Vector Addition

It is used to find the resultant of two non-parallel vectors graphically. And, it is stated as follows.

Triangle law, states that;

"Join the two vectors head to tail and then draw the resultant vector from the tail of the first vector to the head of the second vector."

For example, if we have two vectors $\vec{A}$ and $\vec{B}$ as shown,



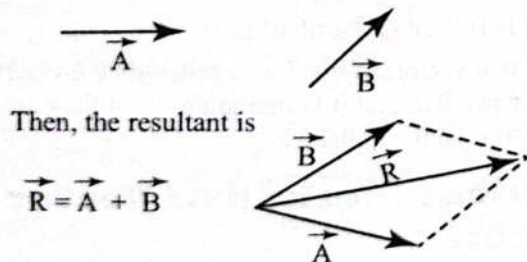
→ The final geometry we get in the triangle law triangle three - sided figure

Parallelogram Law of Vector Addition

It is also used to find the resultant of two non-parallel vectors graphically.

Parallelogram Law, states that: "Join the two vectors tail to tail and form a parallelogram and then draw the diagonal of the parallelogram as resultant vector."

For example, if we have two vectors, $\vec{A}$ and $\vec{B}$ as shown



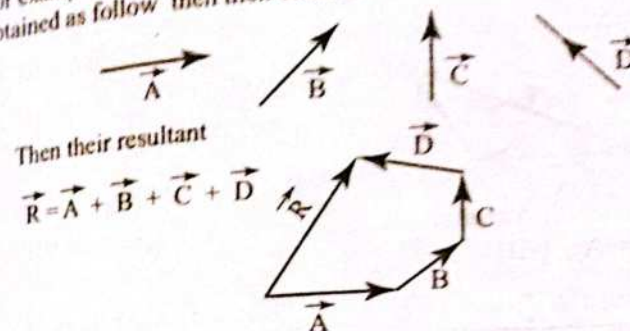
→ The final geometry in the parallelogram law is a four sided figure

Polygon Law of Vector Addition

It is used to find the resultant of more than two vectors and states that

"Join the vectors head to tail and then draw the resultant vector from the tail of the first vector to the head of the last vector."

For example, if we have vectors $\vec{A}$, $\vec{B}$, $\vec{C}$ and $\vec{D}$ then their resultant can be obtained as follow then their resultant



→ The final geometry in the polygon law is a many sided figure

Conceptual Examples

42. If two vectors have equal magnitudes, what will be the maximum and the minimum value of their magnitude
43. What does $\vec{A} - \vec{B}$ mean? Explain
44. If three vectors have unequal magnitudes, can their resultant be zero? Explain
45. What can you say about the resultant of three or more vectors, if they form a polygon when joined head to tail. Explain
46. If we have two vectors $\vec{A}$ and $\vec{B}$ as shown, then graphically find:
 - i. $\vec{A} + \vec{B}$
 - ii. $\vec{A} - \vec{B}$



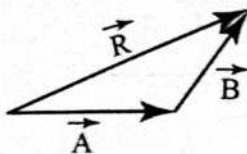
Explanation

42. Assuming a vector has a magnitude of A
maximum = 2A, minimum = 0
43. It means, the sum of $\vec{A}$ and $-\vec{B}$, $\vec{A} + (-\vec{B})$, we reverse the direction of vector $\vec{B}$

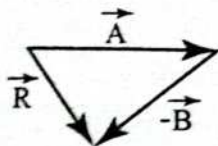
44. Yes! for example, $\vec{A} = 4\text{m, East}$, $\vec{B} = 3\text{m, west}$, $\vec{C} = 1\text{m, west}$

45. It is zero

46. i) $\vec{R} = \vec{A} + \vec{B}$



ii) $\vec{R} = \vec{A} - \vec{B} = \vec{A} + (-\vec{B})$



47. Which combination of basic quantities can define force?

A) Acceleration and mass

C) Acceleration, length and time

B) Mass time and velocity

D) Time, length and mass

Hint:- $F = ma$

$$1\text{N} = 1\text{kg} \frac{\text{m}}{\text{s}^2} = M \frac{L}{T^2}$$

Answer: D

48. Which property of vectors is possible?

A) Vector addition is associative

B) Vector subtraction is commutative

C) The resultant of perpendicular vectors is zero

D) The resultant of parallel vectors is zero.

Hint:- $\vec{C} + (\vec{A} + \vec{B}) = \vec{B} + (\vec{A} + \vec{C})$

$$\vec{A} - \vec{B} = -\vec{B} + \vec{A}$$

$$|\vec{A} - \vec{B}| \leq R \leq |\vec{A} + \vec{B}|$$

Answer: A

49. The resultant of vectors $\vec{A}$ and $\vec{B}$ is 12 units if the magnitude of $\vec{A}$

is 6 units, then that of $\vec{B}$ is

A) Greater than 18 units

C) Less than 6 units

B) $6 \leq B \leq 18$

D) Less than 12 units

Hint:- $|\vec{A} - \vec{B}| \leq R \leq |\vec{A} + \vec{B}|$

$$6 - B \leq 12 \text{ or } 12 \leq 6 + B$$

$$B \leq 18$$

$$B \geq 6$$

Answer: B

50. The magnitude of the resultant of two vectors is minimum then the vectors are

A) Parallel to each other

C) Opposite to each other

B) Perpendicular to each other

D) At 45° to each other

Hint: $|\vec{A} - \vec{B}| \leq R \leq |\vec{A} + \vec{B}|$

(Opposite) (parallel)

Answer: C

51. The x component of a vector of magnitude 25 units is 15 units what is the Y component of the vector?

A) 10 units

B) 20 units

C) 40 units

D) 35 units

Hint: $A = \sqrt{A_x^2 + A_y^2}$

$$(25)^2 = (15)^2 + A_y^2$$

$$A_y = 20 \text{ unit}$$

Answer: B

52. The magnitude of the resultant of two vectors is 20 when they are parallel and 4 when they are opposite to each other. Their magnitudes must be?

A) 8 and 12 units

C) 24 and 16 units

B) 6 and 14 units

D) 10 and 6 units

Hint: $A + B = 20$

$$A - B = 4$$

$$A = 12 \text{ and } B = 8$$

53. A bird flies 4km East and 3km North. What is the resultant displacement of the bird?

A) 5km, 37° East of North

C) 5km, 37° North of East

B) 7 km, 37° East of North

D) 1km, East

Hint: $S = \sqrt{S_1^2 + S_2^2} = \sqrt{3^2 + 4^2}$

$$S = 5\text{Km}, \tan \theta = \frac{3}{4}$$

$$\theta = \tan^{-1}(0.75) = 37^\circ$$

Answer: A

54. The resultant of two forces that are perpendicular to each other is 130N. If one of the vectors is 120N, what is the magnitude of the other vector?

A) 10N

B) 250N

C) 125N

D) 50N

Hint: $130^2 = 120^2 + F^2$

$$F = 50\text{N}$$

Answer: C

55. A cart is pulled by a rope making an angle of 45° by a force of 100N.

What is the magnitude of the vertical component?

A) 45N

B) 70N

C) 60N

D) 100N

Hint: $F_y = F \sin \theta = 100 \sin (45^\circ) = 100 (0.7) = 70\text{N}$

Answer: B

56. A vector of magnitude 10 units has components of A_x equal to 6 unit. What angle does the vector make

with the positive x - axis?

A) 37°

B) 45°

C) 53°

D) 60°

Hint: $\sin \theta = \frac{A_y}{A} = \frac{8}{10}$

$$\theta = \sin^{-1}(0.8)$$

$$\theta = 53^\circ$$

Answer: C

57. Two forces act together on an object. The magnitude of their resultant is least when the angle between them is ?

A) 0°

B) 45°

C) 60°

D) 180°

Hint: $|A - B| \leq R \leq |A + B|$

least

maximum

$$\theta = 180^\circ$$

$$\theta = 0^\circ$$

Answer: D

58. Which of the following pairs of vectors will not produce a resultant of 15

A) 5 and 12 units

C) 10 and 15 units

B) 6 and 8 units

D) 10 and 6 units

Hint: $|A - B| \leq R \leq |A + B|$

Answer: B

End of unit Questions and Problems

I. Give Short Answers to the following Questions

1. What is physics?
2. List branches of physics
3. A person who studies physics is known as?
4. What is unit?
5. What is measurement ?
6. What are significant figures?
7. What is a scientific notation?
8. What are prefixes?
9. What are physical quantities
10. Mention the data measuring scales
11. What is vector resolution?
12. How many seconds are there in one day?
13. If two vectors have equal non-zero magnitudes, can their resultant be zero? Explain

14. In which graphical rule we connect vectors head to tail?
15. Write 0.000005m using
- Scientific notation
 - Prefix
16. The volume of the earth is on the order of $30 \times 10^{21} \text{m}^3$. Write this value using prefix
17. Read and write using prefixes the following numbers
- 1000,000,000
 - 1000,000,000,000
 - 1000,000,000,000,000,
 - 1000,000,000,000,000,000
 - 1000,000,000,000,000,000,000
 - 1000,1000,000,000,000,000,000,000

II. Match the items in column "A" with those in column "B"

A

- No ranking
- Ranking, No precision
- Precise, No true zero
- Has true zero
- 10^0
- $10^1, 10^{-1}$
- $10^2, 10^{-2}$
- $10^3, 10^{-3}$
- $10^6, 10^{-6}$
- $10^9, 10^{-9}$
- $10^{12}, 10^{-12}$
- $10^{15}, 10^{-15}$
- $10^{18}, 10^{-18}$
- $10^{21}, 10^{-21}$
- $10^{24}, 10^{-24}$

B

- Ratio
- Interval
- Nominal
- Ordinal
- Yotta, yocto
- Zetta, zepto
- Exa, atto
- Peta, femto
- Tera, pico
- Giga, nano
- Mega, micro
- Killo, milli
- hecto, centi
- deca, deci
- base

P) Micto, Macta

Answers to End of unit Questions

I. Short Answer and Explanations

- Physics is a branch of natural science that studies about matter, energy and interaction.
- Mechanics, Thermodynamics, optics, Acoustics etc
- Physicist
- SI unit is an internationally accepted standard unit of measurement and stands for system international
- Measurement is a process of comparing an unknown quantity with a standard one of the same type.
- Significant figures are reliable digits obtained in a measurement
- Scientific notation is a simple way of writing very small or very large numbers using a power of ten.
- Prefixes are symbols used in place of power of ten in front of units
- Physical quantities are quantities that can measured directly or indirectly
- Nominal, ordinal, interval and ratio
- Vector resolution is a process of splitting vector in to components
- 1 day = 24 house = (24) (60) (60) = 86400 seconds
- Yes when they act in opposite directions
- Triangle and polygon laws
- 0.0000005m is
 - $5 \times 10^{-6} \text{m}$, scientific notation
 - $5 \mu\text{m}$, prefix
- 10^{21} is zetta, 30 Zm²
- Billion, Giga = 10^9
 - Trillion, Tera = 10^{12}

iii. Quadrillion, Peta = 10^{15} iv. Quintillion, Exa = 10^{18} v. Sextillion, Zetta = 10^{21} vi. Septillion, yotta = 10^{24} **II. Matching Item**

18.C

22.O

26.K

30.G

19.D

23.N

27.J

31.F

20.B

24.M

28.I

32.E

21.A

25.L

29.H

UNIT -3

3. Motion in a Straight Line

3.1 Position Distance and Displacement

3.2 Speed, Velocity and Acceleration

3.3 Equations of Motion with Constant Acceleration

3.4 Graphical Description of Uniformly Accelerated motion

3.5 Relative velocity in one dimension

3. Motion in a Straight Line

Hello there! How do you do? We are very happy to meet you in this fascinating unit where you will be able to define motion, describe motion parameters such as distance, displacement speed, velocity, acceleration and plot their graphs against time and solve problems related to motion of bodies in a straight line. You will Love it.

3.1 Position, Distance and Displacement

Motion of a body can only be explained by considering its position from a give point as time passes. Hence, to define motion, first we need to be clear about the concept of position and reference frame.

Position: Is the location of a body from a specific reference point.

For example, as you move from home to school, your initial position is home your final position is school.

Conceptual Example

1. Can the position of a body be negative? Explain

Explanation:

Yes, when the body moves or located to the left side or down side of the origin.

- ☒ The motion of a body is expressed using a particular reference point called the *frame of reference*

Frame of Reference: Is a point that is used to determine position of body.

- ☒ A point of reference, that is, a reference frame may be at rest or in motion.

N' let's see how motion of a body is defined,

Motion: Is a continuous change in position of a body with respect to a fixed point as time passes.

Therefore, a body is said to be in motion only if it changes its position relative to some fixed reference frame as time goes.

Conceptual Example

2. If a body is observed moving in one reference frame, can we conclude that the body is also moving in all other reference frames? Explain

Explanation:

No! For example, if you are in a car that is moving at 100km/hr, then you are moving at that speed when observed by a person standing by the road but you are not moving as seen by a person sitting next to you in the car.

As a body moved from one point to the other, it covers some distance.

Distance (S) : Is the actual path length travelled by a moving body

Distance, is a scalar quantity and its SI unit is meter (m).

And, depend-ling on the path length to be measured, we may use non - SI units such as micrometer (Nm), millimetre (mm), centimetre (cm), kilometre (km) etc.

Conceptual Examp

3. Can the distance covered by a body be negative ? Explain.

Explanation:

Never. A moving body covers non-zero and non-negative distance. When a body moves, it changes its position as time passes.

Displacement ($\vec{S}$) : Is the change in position of a body in a specific direction

Displacement, is a vector quantity and its SI unit is meter (m)

- ☒ Displacement of a body tells us how far and in which direction the body is now from its starting point.

Therefore, displacement of a body is the shortest or short cut distance

of the body between its initial and final positions.

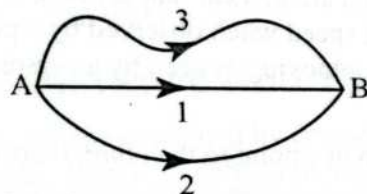
Conceptual Example

4. Can displacement of a body become negative or zero? Explain

Explanation:

Yes, It became negative when the body moves to the left or down ward from the origin and it became zero when the body returned to its starting point.

5. If a body moved from point A to point B along three different paths as shown, which path represent displacement of the body? And why?



Explanation:

Path -1 Because, it is the shortest path length of the body from its initial position to its final position.

The difference between distance and displacement is given in the following table.

Distance	Displacement
☒ Actual path length	☒ Shortest path length
☒ Scalar quantity	☒ Vector quantity
☒ Depends on path followed	☒ Depends on initial and final position
☒ Always positive	☒ Can be zero, negative or positive
☒ Greater than or equal to displacement	☒ Less than or equal to distance
☒ Distance and displacement have the same SI unit, meter (m)	

Illustrative Example

6. If a bus moved 800m due east along a straight road and then 300m due west along the same road, then what are the distance and displacement of the bus?

7. Suppose your school is 1km away. If you return home after class along the same route. What is your entire trip?

A. Distance

B. Displacement for the

8. If a body moved 300m due east and then 400m due north, then what are the distance and displacement of the body?

9. If an athlete runs once along circular track of radius 400m, then what are the distance and displacement of the athlete?

Solution

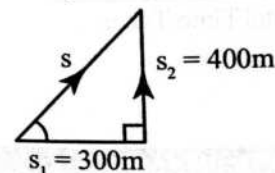
6. Distance = 800m + 300m = 1100m, and

Displacement = 800m - 300m = 500m due East

7. Distance = 1km + 1km = 2km = 2000m, and

Displacement = 1km - 1km = Zero

8. The path of the body can be visualized as follows.



A. Distance = $s_1 + s_2 = 300\text{m} + 400\text{m}$

B. Displacement = $\sqrt{s_1^2 + s_2^2} = \sqrt{(300)^2 + (400)^2} = \sqrt{250000}$

$S = 500\text{m}$, North of East

9. Distance = $2\pi r = 2 (3.14) (400) = 2512\text{m}$

Displacement = 0, zero

3.2 Speed, Velocity and Acceleration

As a body move, it may be faster or slower and the quantity that describes how fast a body is moving is called *speed*.

Speed: Is the rate at which a body changes its location

Mathematically, speed of a body is calculated as follows;

$$\text{Speed} = \frac{\text{Distance Travelled}}{\text{Time Taken}}$$

$$V = \frac{s}{t}$$

Speed is a scalar quantity and its SI unit is meter per second (m/s). other non - SI units of speed include kilo meter per hour (km/h) and miles per hour (mi/h).

For different reasons, a body may not move at constant speed through out its journey history. At one time the body may move faster and at another time, it may move slower. Therefore, we need to consider average speed to talk about the over all speed of the body during its entire trip.

Average Speed: Is the speed that a body attained to cover the total distance.

Mathematically, average speed of a body is obtained by.

$$\text{Average Speed} = \frac{\text{Total Distance Travelled}}{\text{Total Time Taken}}$$

$$V_{av} = \frac{S_T}{t_T}$$

Conceptual Example

10. What does the speedometer of a car measure?

Explanation:

Speedometer in a car measures instantaneous speed of the car, that is the speed of the car at a specific instant of time

11. Can the average speed of a moving body ever be zero? Explain

Explanation:

Never! Average speed of a body can not be zero. But, at some instants of time, the body may have zero speed during the moments it stopped in its journey history.

Illustrative Examples

12. If a car travelled 81 km in 1 hour and 30 minutes, what is its average speed?
13. A boy walked a distance of 400m in 5 minutes and run a distance of 800m for 3 minutes. What is the average speed of the boy?
14. A motor-cycle moved a distance of 200m at a speed of 10m/s and a distance of 600m at a speed of 20 m/s. What is the average speed of the motor?
15. A cheetah can run at 30m/s. How far will it travel in 12 seconds?
16. An athlete runs a rectangular field of side 100m by 80m in one minute. What is average speed?
17. If a car moved a distance of 500m at a speed of 400 km/h and returned, at a speed of 60km/h to its initial position along the same road, what is its average speed of the athlete?

Solution

$$12. V_{av} = \frac{S_T}{t_T} = \frac{81 \text{ km}}{1 \text{ hour} + 0.5 \text{ hour}} = \frac{81000 \text{ m}}{5400 \text{ sec}} = 15 \text{ m/s}$$

$$13. V_{av} = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t_1 + t_2} = \frac{400 + 800}{5(60) + 3(60)} = \frac{1200}{480} = 2.5 \text{ m/s}$$

$$14. V_{av} = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t_1 + t_2},$$

$$t_1 = \frac{S_1}{V_1} = \frac{200}{10} = 20 \text{ sec}$$

$$t_2 = \frac{S_2}{V_2} = \frac{600}{20} = 30 \text{ sec}$$

$$V_{av} = \frac{800}{50} = 16 \text{ m/s}$$

$$15. S = vt = (30)(12) = 360 \text{ m}$$

$$16. V_{av} = \frac{S_T}{t_T} = \frac{2(100 + 80)}{60} = \frac{360}{60} = 6 \text{ m/s}$$

$$17. V_{av} = \frac{S_T}{t_T} = \frac{S_1 + S_2}{t_1 + t_2} = \frac{S_1 + S_2}{\frac{S_1}{V_1} + \frac{S_2}{V_2}}$$

$$= \frac{2S}{S(v_1 + v_2)} = \frac{2v_1 v_2}{v_1 + v_2}$$

$$V_{av} = \frac{2(40)(60)}{40 + 60}$$

$$= \frac{4800}{100} = 48 \text{ km/h}$$

For a moving body, its speed alone may not give complete description about the nature of its motion. Therefore, to answer the question, how fast and in which direction a body is moving, we use a concept called **velocity**.

Velocity: Is the rate of change of displacement in a unit time

Mathematically, velocity of a body is calculated as :

$$\text{Velocity} = \frac{\text{change in Displacement}}{\text{Time Taken}}$$

$$\vec{V} = \frac{\Delta \vec{S}}{\Delta t}$$

Velocity is a vector quantity and its SI unit is meter per second (m/s). It can also be expressed using km/h or mi/h.

→ The magnitude of velocity is speed of the body.

Conceptual Examples

18. Can a body have a constant velocity and varying speed at time? Explain

Explanation:

No! Constant velocity means steady speed in a specific direction.

19. Can a body have a Constant Speed and a Varying Velocity at the same time? Explain

Explanation:

Yes! This is possible when a body moves in a circular path at steady speed.

20. A man leaves his house for a cycle ride, and comes back to his house

after half an hour, covering a total distance of 5km. What can you say about the average velocity of the man?

Explanation:

$$\vec{V}_{av} = \frac{\Delta \vec{S}}{\Delta t} = 0, \text{ Zero}$$

Illustrative Example

21. A car moved 500m due east in 15 seconds and then 300m due west in 5 seconds. What is the car's
 - A. Average speed
 - B. Average velocity
22. A boy walks 400m East and then 300m north in just 20 seconds. Find the boy's
 - A. Average speed
 - B. Average velocity
23. An athlete runs a circular track of radius 400m in just 40 seconds. What is the athlete's
 - A. Average speed
 - B. Average velocity

Solution

$$21. A) V_{av} = \frac{S_1 + S_2}{t_1 + t_2} = \frac{500 + 300}{15 + 5} = \frac{800}{20} = 40 \text{ m/s}$$

$$B) \vec{V}_{av} = \frac{\Delta S}{\Delta t} = \frac{S_2 - S_1}{15 + 5} = \frac{300 - 500}{20} = -10 \text{ m/s, West}$$

$$\vec{V}_{av} = 10 \text{ m/s, East}$$

$$22. A) V_{av} = \frac{S_1}{t_1} = \frac{S_1 + S_2}{t} = \frac{400 + 300}{20} = 35 \text{ m/s}$$

$$B) \vec{V}_{av} = \frac{\Delta S}{\Delta t} = \frac{\sqrt{S_1^2 + S_2^2}}{t} = \frac{\sqrt{(400)^2 + (300)^2}}{20} = 25 \text{ m/s, North of East.}$$

$$23. A) V_{av} = \frac{S_1}{t_1} = \frac{2\pi r}{t} = \frac{2(3.14)(400)}{40} = 62.8 \text{ m/s}$$

$$B) \bar{V}_{av} = \frac{\Delta S}{\Delta t} = 0, \text{ zero.}$$

Conceptual Examples

24. Is there any difference between average velocity and instantaneous velocity of a body? Explain

Explanation:

Yes there is! Average Velocity is the over all velocity of a body for its entire trip. While, instantaneous velocity is the velocity of the body at a particular instant of time.

$$\text{In symbol, } \bar{V}_{av} = \frac{\Delta S}{\Delta t}$$

$$\bar{V}_{inst} = \frac{\Delta S}{\Delta t} \text{ as } \Delta t \text{ approaches zero,}$$

25. If the average velocity of a body is found to be zero, can we conclude that its instantaneous velocity is also zero? Explain

Explanation:

No! A moving body can have zero average velocity when it returns to its initial position, but during its journey history, it might have been moving faster, slower or might have stopped at some instants of time.

When a body changes its velocity, that is speeds up, slows down or changes its direction of motion, we say, the body is *accelerating*.

26. If the average velocity of an object is zero in some time interval, what can you say about the displacement if the object for the interval?

Answer: The displacement is **zero**, since the displacement is proportional to average velocity.

Acceleration Is the rate of change of velocity per unit time.
Mathematically, acceleration of a body is calculated as

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}} = \frac{\text{Final velocity} - \text{Initial velocity}}{\text{Time taken}}$$

$$\bar{a} = \frac{\Delta \bar{V}}{\Delta t} = \frac{V - u}{t}$$

Acceleration is a vector quantity and its SI unit is meter per second square (m/s^2)

A body is said to accelerate when there is change in its speed, in its direction or in both. A body at rest has zero initial velocity and a body coming to rest has zero final initial velocity. Moreover, when a body slows down, its acceleration became negative and we call the body is *decelerating*.

Conceptual Examples

27. Can a body of zero velocity accelerate? Explain

Explanation:

Yes, For example, a body thrown up ward has zero velocity at its maximum height but is still accelerating.

28. If the acceleration of a body is zero, does it mean that its velocity is also zero? Explain

Explanation:

No! For example, when a body moves at constant speed in a straight line, its acceleration is zero but its velocity is none - zero constant.

29. Can the acceleration of a body has opposite direction to its velocity? Explain

Explanation:

Yes! When a body slows down, its acceleration has opposite direction to its velocity.

30. When a body decelerates, that is slows down, will it have necessary a negative acceleration? Explain

Explanation:

No. Not necessary! For example, if a body that moves in the negative

x - direction slows down, then its acceleration is positive that points to the positive x- direction.

The acceleration of a body at a specific instant of time is called instantaneous acceleration. Mathematically, instantaneous acceleration is obtained by

$$\bar{a}_{\text{inst.}} = \frac{\Delta \bar{v}}{\Delta t} \text{ as } \Delta t \text{ approaches zero}$$

31. What does it mean when we say the acceleration of a body is 3m/s^2 ? Explain

Explanation:

It means, the velocity of the body is increasing by 3m/s every second. There fore, the body has 3m/s in the first second, 6m/s in the next second, 9m/s in the third second, ... etc

Illustrative Examples

32. What is the acceleration of a train if it speeds up from 20m/s to 50m/s in 5 seconds?

Solution

$$a = \frac{v - u}{t} = \frac{50 - 20}{5} \\ = 6\text{m/s}^2$$

33. If a car accelerates at a rate of 4m/s^2 starting from rest, how long will it take the car to reach a speed of 12m/s ?

Solution:

$$\text{From, } a = \frac{v - u}{t} \\ t = \frac{v - u}{a} = \frac{12 - 0}{4} \\ = 3\text{sec.}$$

34. An ambulance moving at 144km/h takes 10 seconds to slow down to 10m/s . What is its acceleration?

Solution

$$a = \frac{v - u}{t}, u = 144\text{km/h} = 40\text{m/s}$$

$$a = \frac{10 - 40}{10} = -3\text{m/s}^2$$

- ✓ The minus sign tells us, the acceleration is opposite in direction to the velocity.

35. If a taxi moving at 10m/s accelerate at 2m/s^2 . What will be its velocity after 5 seconds?

Solution

$$\text{We know, } a = \frac{v - u}{t} \\ v = u + at = 10 + (2)(5) \\ = 20\text{m/s}$$

36. If a car moving at constant acceleration of 3m/s^2 attained velocity of 20m/s in 4seconds, what was its initial velocity?

Solution

$$\text{From, } a = \frac{v - u}{t} \\ u = v - at = 20 - (3)(4) \\ = 8\text{m/s}$$

In actual cases, a moving body may speed up, slow down or change its direction of motion. But, in some ideal and rare case, a body may travel at constant speed through its journey history. In such cases, the body is said to be in *uniform motion*.

Uniform Motion: Is the motion of a body at a constant speed.

- ✓ A body in a uniform motion covers equal distance in equal intervals of time and has zero acceleration. More over if the body is moving in a straight line, its average and instantaneous velocities have the same values at all times.

Illustrative Example

37. If a body has the following journey history, in a straight line, then find,
A. The instantaneous velocity for each time interval
B. The average velocity

- C. The acceleration of the body
D. Is the body under uniform motion? Why?

Distance (m)	0	10	20	30	40	50
Time (s)	0	1	2	3	4	5

Solution

$$A) V_1 = \frac{S_1}{t_1} = \frac{10}{1} = 10 \text{ m/s}$$

$$V_2 = \frac{S_2}{t_2} = \frac{20}{2} = 10 \text{ m/s}$$

$$V_3 = \frac{S_3}{t_3} = \frac{30}{3} = 10 \text{ m/s}$$

$$V_4 = \frac{S_4}{t_4} = \frac{40}{4} = 10 \text{ m/s}$$

$$V_5 = \frac{S_5}{t_5} = \frac{50}{5} = 10 \text{ m/s}$$

$$B) V_{av} = \frac{S_T}{t_T} = \frac{50}{5} = 10 \text{ m/s}$$

$$C) a = \frac{\Delta V}{\Delta t} = \frac{10-10}{1} = 0, \text{ zero}$$

D) Yes, the body is in a uniform motion since its speed is constant.

3.3 Equations of Motion with Constant Acceleration

If the velocity of a body increase or decreases by equal amounts in equal intervals of time, then the acceleration of the body be came constant and the body is said to be in a *uniform acceleration motion*.

The motion parameters such as velocity, acceleration displacement and time taken of a body in a uniform motion are related by simple set of equations known as *the equations of motion*.

Now let's derive the equations of motion using the definition of acceleration and average velocity.

Acceleration, $a = \frac{V-u}{t}$, then the final velocity is

$$V = u + at \quad \text{----- (1)}$$

$$\text{Average Velocity, } V_{av} = \frac{s}{t}, V_{av} = \frac{V+u}{2}$$

$$S = \left(\frac{v+u}{2} \right) t \quad \text{----- (2)}$$

Substitute, $v = u + at$, in to equation (2), we get,

$$S = \left[\frac{(u+at)+u}{2} \right] t$$

$$S = ut + \frac{1}{2} at^2 \quad \text{----- (3)}$$

Again, substituting, $t = \frac{v-u}{a}$, in to equation (2), we obtain,

$$s = \left(\frac{v+u}{2} \right) \left(\frac{v-u}{a} \right)$$

$$v^2 = u^2 + 2as \quad \text{----- (4)}$$

Illustrative Examples

38. A car accelerates at 2 m/s^2 starting from rest, what will be its velocity after 10 seconds?

Solution

$$V = u + at = 0 + (2)(10) \\ = 20 \text{ m/s}$$

39. An automobile accelerates at 4 m/s^2 starting from rest. What distance will it cover in 10 seconds?

Solution

$$S = vt + \frac{1}{2} at^2 = (0)10 + \frac{1}{2} (4)(10)^2 \\ = 200 \text{ m}$$

40. An airplane moving at 100 m/s decelerates uniformly at 6 m/s^2 . What will be its speed as it moved 800 m along the run - way?

Solution

$$V^2 = u^2 + 2as = (100)^2 + (2)(-6)(800) = 400$$

$$V = 20 \text{ m/s}$$

41. A racing car is travelling at 10m/s. It accelerates uniformly and covers a distance of 725m in 10 sec. Calculate the acceleration of the car

Solution

$$S = ut + \frac{1}{2}at^2 \Rightarrow 725 = (10)(10) + \frac{1}{2}a(10)^2$$

$$a = 12.5 \text{ m/s}^2$$

42. A truck gradually starts off from rest with a uniform acceleration of 2 m/s^2 and reaches a velocity of 16m/s. Calculate the distance it covered

Solution

$$V^2 = u^2 + 2as$$

$$S = \frac{v^2 - u^2}{2a} = \frac{(16)^2 - (0)^2}{2(2)}$$

$$= 64 \text{ m}$$

43. A car moving with constant acceleration covers the between two points 100m apart in 10 seconds. If its speed as it passes the second point is 15m/s. Then, what is

A. Its speed at the first point

B. Its acceleration

Solution

$$\text{A) } S = \frac{(V+u)t}{2} \Rightarrow u = \frac{2(s)}{t} - v = \frac{2(100)}{10} - 15 = 5 \text{ m/s}$$

$$\text{B) } a = \frac{V-u}{t} = \frac{15-5}{10} = 1 \text{ m/s}^2$$

44. A Volkswagen and a Cadillac are driven on the same 120km trip. The Volkswagen travels at 80km/h all the time. The Cadillac driving at 100km/h stops for ten minutes after travelled for half an hour. Which car is the first to arrive at the destination?

Solution

$$\text{The volkswagen takes, } t_v = \frac{S}{V_v} = \frac{120}{80} = 1.5 \text{ h, and the cadillac}$$

$$\text{takes, } t_c = \frac{S}{V_c} = \frac{120}{100}$$

$$= 1.2 \text{ h. And, since it was not moving}$$

For 10 minutes, the total time it was on the road is then $t_c = 1.2 \text{ h} + 10 \text{ min} = 1.4 \text{ h}$ since $t_c < t_v$, it is the Cadillac that arrived first at the destination.

45. A cyclist starts from rest and accelerates at 1 m/s^2 for 20 second. He then travels at a constant speed for 1 minute and finally decelerates at 2 m/s^2 until he stops. Find:

A. His maximum speed

B. The total distance he covered

Solution

$$\text{First Phase, } V = u + at = 0 + (1)(20) = 20 \text{ m/s}$$

$$S_1 = ut + \frac{1}{2}at^2 = (0)(20) + \frac{1}{2}(1)(20)^2 = 200 \text{ m}$$

$$\text{Phase Two, } S_2 = Vt = (20)(60) = 1200 \text{ m}$$

$$\text{Phase Three, } S_3 = \frac{V^2 - u^2}{2a} = \frac{0 - (20)^2}{2(-2)} = 100 \text{ m}$$

$$\text{A. } V = 20 \text{ m/s}$$

$$\text{B. } S = s_1 + s_2 + s_3 = 1500 \text{ m}$$

46. A taxi moving at 30m/s is forced to stop in 5 seconds due to an electric pole blocking the road 85m ahead. If the driver's reaction time is 0.3 second, could he manage avoiding collision with the pole?

Solution

Total stopping distance is reaction distance plus braking distance

$$S = S_r + S_b = ut_r + \left(\frac{V+u}{2} \right) t = (30)(0.3) + \left(\frac{0+30}{2} \right) 5$$

$$= 84 \text{ m}$$

47. A bus initially at rest accelerates to a speed 25m/s in 4 seconds. What is the distance covered by the bus in the fourth second?

Solution

$$S_n^{\text{th}} = u + \frac{a}{2} (2t-1),$$

$$a = \frac{v-u}{t} = \frac{25-0}{4} = 6.25 \text{ m/s}^2$$

$$S_n^{\text{th}} = 0 + \frac{6.25}{2} [2(4)-1] = 21.9 \text{ m}$$

48. A car is accelerating uniformly as it passes two checkpoints that are 30m apart. The time taken between checkpoints is 4 seconds and the car's speed at the first checkpoint is 5m/s. Find.

A. The acceleration of the car

B. Its speed at the second checkpoint

Solution

$$\text{A) } S = ut + \frac{1}{2} at^2 \Rightarrow 30 = \frac{1}{2} a (4)^2 \Rightarrow a = 1.25 \text{ m/s}^2$$

$$\text{B) } V = u + at = 5 + (1.25)(4) = 10 \text{ m/s}$$

49. The velocity of a train reduces from 15m/s to 7m/s while travelling a distance of 80m. How much further will the train travel before coming to rest provided the acceleration is constant.

Solution

$$S_1 = \frac{V_1^2 - u_1^2}{2a} \text{ and } S_2 = \frac{V_2^2 - u_2^2}{2a}, \text{ Taking Ratio}$$

$$\frac{S_2}{S_1} = \frac{V_2^2 - u_2^2}{V_1^2 - u_1^2}$$

$$\frac{S_2}{80} = \frac{0 - (7)^2}{(15)^2 - (7)^2}$$

$$S_2 = 22 \text{ m}$$

50. A body moving with constant deceleration of 5m/s² covers a 30m distance in 3 seconds. How far will the body travel before coming to rest?

Solution

$$S_1 = V_1 t - \frac{1}{2} at^2 \Rightarrow$$

$$V_1 = \frac{2S_1 + at^2}{2t} = \frac{(2)(30) + (-5)(3)^2}{2(3)} = 2.5 \text{ m/s}$$

$$S_2 = \frac{V_2^2 - u_2^2}{2a} = \frac{0 - (2.5)^2}{2(-5)} = 0.625 \text{ m}$$

51. If a body moving with uniform acceleration covers 15m in the third second and 25m in the eighth second. How much will it travel in the tenth second?

Solution

$$S_n^{\text{th}} = u + \frac{a}{2} (2t-1)$$

$$15 = u + \frac{a}{2} (2(3)-1) \text{ --- (1)}$$

$$25 = u + \frac{a}{2} (2(8)-1) \text{ --- (2)}$$

Solving the two equations simultaneously, we get, $a = 2 \text{ m/s}^2$, $u = 10 \text{ m/s}$

$$\text{Hence, } S_{10}^{\text{th}} = 10 + \frac{2}{2} (2(10)-1) = 29 \text{ m}$$

52. A car starting from rest moves with constant acceleration and reached a velocity of 20m/s. What was the velocity of the car at the middle of the trip?

Solution

$$S = \frac{V^2 - u^2}{2a}, \text{ and at the middle}$$

$$\frac{S}{2} = \frac{(V^*)^2 - u^2}{2a}, V^* \text{ is velocity at mid-point}$$

$$V^* = 10\sqrt{2} \text{ m/s}$$

53. Two cars A and B, at the same initial position accelerate uniformly from rest. After 5 seconds, A is 2m ahead of B. What will be their separation after 8 seconds?

Solution

$$\text{First case, } S_A = \frac{1}{2} a_A t^2 \text{ and } S_B = \frac{1}{2} a_B t^2$$

$$\text{And, } S_A - S_B = \frac{1}{2} t^2 (a_A - a_B) \Rightarrow a_A - a_B = 0.25 \text{ m/s}^2$$

$$\text{Second case, } S_A - S_B = \frac{1}{2} t^2 (a_A - a_B) = \frac{1}{2} (8)^2 [0.25]$$

$$S_A - S_B = 8 \text{ m}$$

54. A car starting from rest accelerates at 4 m/s^2 . If it travelled 40 m in the last second, what is the total distance covered by the car?

Solution

$$S_n^{\text{th}} = u + \frac{a}{2} (2t_n - 1) \Rightarrow 40 = 0 + \frac{4}{2} (2t_n - 1) \Rightarrow t = 10.5 \text{ sec}$$

$$S = ut + \frac{1}{2} at^2 = 0(10.5) + \frac{1}{2} (4)(10.5)^2$$

$$= 220.5 \text{ m}$$

55. A careless Motorist travelling at 90 km/h passes a police car moving at 50 km/h . Immediately, the police car starts accelerating at 3 m/s^2 . At what distance will the police catch the motorist?

Solution

$$Vt = ut + \frac{1}{2} at^2$$

$$V = u + \frac{1}{2} at$$

$$t = 7.4 \text{ sec}$$

$$S = Vt = (25)(7.5) = 18 \text{ m}$$

56. Two sport cars start from rest and move one after the other in 1 minute interval with an acceleration of 0.4 m/s^2 each. How long after the first car starts moving will the distance between them be 4200 m ?

Solution

$$S_1 - S_2 = \frac{1}{2} at_1^2 - \frac{1}{2} at_2^2, t_2 = t_1 - 60$$

$$4200 = \frac{1}{2} (0.4) [t_1^2 - (t_1 - 60)^2]$$

$$t_1 = 145 \text{ seconds}$$

57. A bullet moving with a speed 200 m/s can penetrate a 4 cm thick block. What should be the speed of the bullet to penetrate a 10 cm thick block of the same material?

Solution

$$\text{From, } V^2 = u^2 + 2as \text{ un}\sqrt{s}$$

$$\frac{u_2}{u_1} = \frac{\sqrt{S_2}}{\sqrt{S_1}} \Rightarrow u_2 = u_1 \sqrt{\frac{S_2}{S_1}} = 200 \sqrt{\frac{10}{4}}$$

$$u_2 = 316 \text{ m/s}$$

58. A bus is beginning to move with an acceleration of 1 m/s^2 . A boy who is 48 m behind the bus starts running at 10 m/s . After what time will he catch the bus?

Solution

Distance moved by the boy Distance moved by the bus

$$S_1 = S_2$$

$$Vt = 48 + \frac{1}{2} (a) t^2$$

$$10t = 48 + \frac{1}{2} t^2$$

$$\Rightarrow t^2 - 20t + 96 = 0 \text{ using the quadratic equation}$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = 8 \text{ sec or } t = 12 \text{ sec}$$

Earlier time, $t = 8 \text{ sec}$

59. The motion of a body is given by the equation, $V = mt + n$ where m is 5 m/s^2 and n is 10 m/s . How far will it travel in the first 2 seconds?

Solution

$$V = mt + n = 5t + 10 = u + at$$

$$\text{Hence, } u = 10 \text{ m/s and } a = 5 \text{ m/s}^2$$

$$\Rightarrow S = ut + \frac{1}{2} at^2 = (10)^2 + \frac{1}{2} (5)(2)$$

$$= 30 \text{ m}$$

60. Show that the distance moved by a body in the n^{th} second is obtained

$$\text{by: } S_n^{\text{th}} = u + \frac{a}{2} (2t_n - 1)$$

$$S_n^{\text{th}} = S_n - S_{n-1}$$

$$= \left[ut_n + \frac{1}{2} at_n^2 \right] - \left[u(t_n - 1) + \frac{1}{2} a(t_n - 1)^2 \right]$$

$$= ut_n + \frac{1}{2} at_n^2 - \left[ut_n - u + \frac{1}{2} a(t_n^2 - 1) \right]$$

$$= ut_n + \frac{1}{2} at_n^2 - ut_n + u - \frac{1}{2} at_n^2 + \frac{2t_n a}{2} - \frac{1}{2} a$$

$$= u + \frac{2t_n a}{2} - \frac{1}{2} a$$

$$= u + a \left[t_n - \frac{1}{2} \right]$$

$$= u + \frac{a}{2} (2t_n - 1)$$

Warning: The equations of motion we used so far are applicable only for a body that is uniformly accelerating.

Typical example of a body in uniform acceleration is free fall. A body thrown or released in air move towards the centre of the earth at a constant acceleration called *acceleration due to gravity*.

Free Fall: Is a body that move in air due to the influence of gravity alone.

Near the surface of the earth, a freely falling body moves at a constant gravitational acceleration of $g = 9.81 \text{ m/s}^2$.

The equations of motion for a free fall are the same as those used for a uniformly accelerated motion in a straight line except some symbol and sign modifications.

So here, we use 'g' for 'a' and 'y' or 'h' for 's' and in this book we use positive sign for 'g' when the motion is downward and negative sign for an upward motion. There fore, we can have the following cases.

For a body dropped $u = 0$	For a body thrown down ward $u \neq 0$	For a body thrown up ward $u \neq 0$
$V = gt$	$V = u + gt$	$V = u - gt$
$y = \frac{1}{2} gt^2$	$y = ut + \frac{1}{2} gt^2$	$y = ut - \frac{1}{2} gt^2$
$V^2 = 2gy$	$V^2 = u^2 + 2gy$	$V^2 = u^2 - 2gy$

☑ A body is in free fall as soon as it is released in to the air weather it is dropped, or thrown in any direction and in the absence of air resistance, all bodies fall with the same acceleration regardless of their mass.

Conceptual Example

61. What will happen to the velocity and acceleration of a body that is thrown upward when it reached the maximum height? Explain

Explanation:

At the maximum height, the velocity of the body is zero but its acceleration remains 9.81 m/s^2 .

Illustrative Example

62. A ball is kicked upward with an initial speed of 20 m/s from the ground, use $g = 10 \text{ m/s}^2$ and calculate,

- The speed of the ball at $t = 2$ second
- The maximum height reached by the ball
- The time the ball takes to return to the ground

Solution

$$\text{A. } V = u - gt = 20 - (10)(2) = 0, \text{ zero}$$

$$\text{B. } V^2 = u^2 - 2gh_{\text{max}}, V = 0 \text{ at } h_{\text{max}}$$

$$h_{\text{max}} = \frac{u^2}{2g} = \frac{(20)^2}{2(10)} = 20 \text{ m}$$

$$\text{C. } Y = ut - \frac{1}{2} gt^2, y = 0$$

$$0 = ut - \frac{1}{2} gt^2$$

$$t = \frac{2u}{g} = \frac{2(20)}{10} = 4 \text{ second}$$

63. At the time a ball is dropped from the top of a 20m building, a stone is thrown up ward from the ground. If they both hit the ground at the same time, what was the initial velocity of the stone?

Solution

$$\text{For the ball, } Y = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2(20)}{10}} = 2 \text{ sec}$$

$$\text{For the stone, } Y = ut - \frac{1}{2}gt^2 = 0$$

$$u(2) = \frac{1}{2}(10)(2)^2$$

$$u = 10 \text{ m/s}$$

64. From what height did a body fall if its speed as it strikes the ground is 30m/s?

Solution

$$V^2 = u^2 + 2gy, u = 0$$

$$Y = \frac{V^2}{2g} = \frac{(30)^2}{2(10)} = 45 \text{ m}$$

65. A stone is released from the top of 180m cliff. If one second later a ball is thrown down and both hit the ground at the same time, with what speed was the ball thrown?

Solution

$$\text{For the stone, } Y = ut_s - \frac{1}{2}gt_s^2 \Rightarrow t_s = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2(180)}{10}} = 6$$

$$\text{For the ball, } Y = ut_b + \frac{1}{2}gt_b^2, t_b = t_s - 1 = 6 - 1 = 5 \text{ sec}$$

$$\text{Therefore, } 180 = 5u + \frac{1}{2}(10)(5)^2$$

$$u = 61 \text{ m/s}$$

66. An object is thrown down ward with initial speed of 12m/s from a 20m high building. Describe how the height of the object varies with time.

Solution

The height of the object from the ground at any time is

$$Y = 20 - (ut + \frac{1}{2}gt^2)$$

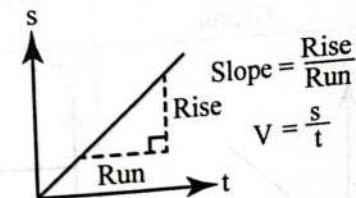
$$Y = 20 - ut - \frac{1}{2}gt^2$$

3.4 Graphical Description of Uniformly Accelerated Motion

A graphical description of motion of a body is a powerful means that help us to easily visualize the nature of motion of a body under consideration. To plot a motion graph, we label the independent variable that is time along the x-axis and the dependent variable such as displacement, velocity and acceleration along the y-axis with the appropriate scales.

Distance - Time Graph (s - t) Graph

For a uniform motion in a straight line, the s - t graph is a straight line that passes through the origin.

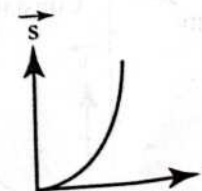


- ☑ Slope of the distance - time graph represents *speed* of the body

Displacement - Time Graph, ($\bar{s}$ - t) Graph

For a uniformly accelerated motion,

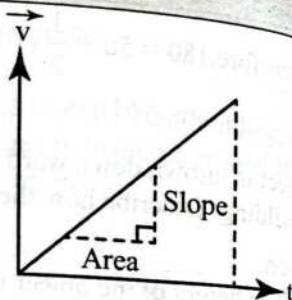
the $\bar{v}$ - t graph is half - parabola as shown in the sketch.



- ☑ Slope of displacement - time graph represent *velocity* of the body

Velocity - Time Graph, ($\vec{v}$ - t) Graph

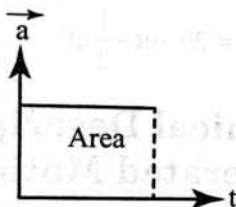
For a uniformly accelerated motion, the $\vec{v}$ - t graph is a straight line that passes through the origin, if the body started from rest.



- ☑ The slope of a velocity - time graph represents *acceleration* of the body and the area under the velocity - time curve represents *displacement* of the body.

Acceleration - time Graph, ($\vec{a}$ - t) graph

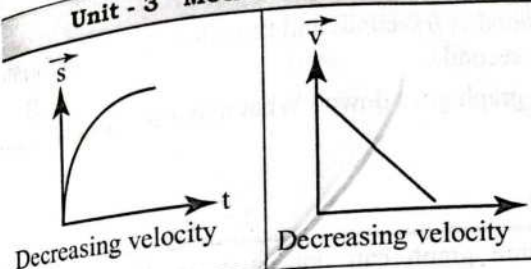
For a uniformly accelerated motion, the $\vec{a}$ - t graph is a horizontal line parallel to the time axis as shown



- ☑ The area under the acceleration - time graph represents the *change in velocity* of the body.

Some of the typical motion graphs are the following.

Displacement - Time Graph	Velocity - Time Graph	Acceleration - Time Graph
Constant velocity	Constant velocity	Postive acceleration
Increasing velocity	Increasing velocity	Negative acceleration

**Conceptual Example**

67. Is there any difference between uniform motion and uniformly accelerated motion? Explain

Explanation

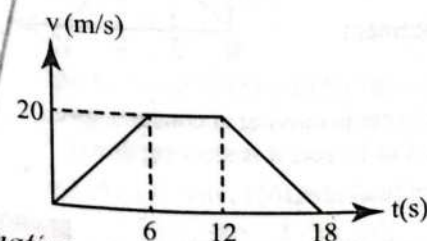
Yes! In a uniform motion in a straight line, the velocity is constant and the acceleration is zero. But, in a uniformly acceleration motion, the velocity changes and the acceleration is constant.

68. Why is the distance - time graph straight while, the displacement - time graph is parabolic? Explain

Explanation

Because, in a uniform motion, the speed is constant, and distance is obtained by $s = vt$, 1st degree linear. While in a uniformly accelerated motion, the speed varies and displacement is obtained by $s = ut + \frac{1}{2}at^2$, 2nd degree quadratic.

69. Describe the nature of motion of a car whose velocity varies with time as shown below

**Explanation**

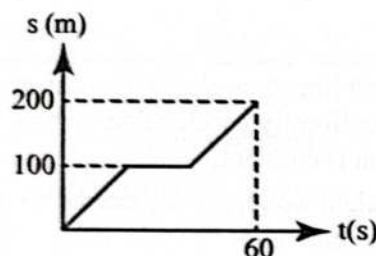
The car starts from rest and reached a velocity of 20m/s in 6 seconds and

moved at this rate for another 6 seconds and then slows down uniformly and comes to rest in 6 seconds.

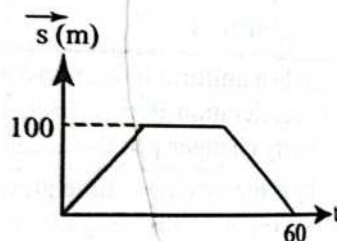
70. Can the distance time graph goes down? What about the displacement time graph? Explain

Explanation

Never! Distance - time graph can not have negative slope, but displacement - time graph can have, such a slope. For example, if you walk 100m due east and return to your initial position in 60 seconds along the same route, your distance - time and displacement - time graph looks the following



Distance - Time Graph

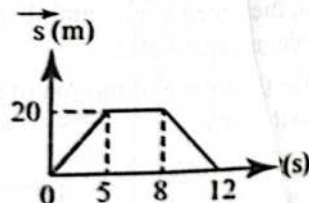


Displacement - Time Graph

Illustrative Examples

71. If a car experienced a displacement - time graph as follows

- State the nature of its motion
- Calculate its total distance
- Calculate its velocities
- What is its displacement



Solution

- A. From 0 to 5 sec, the car is moving at constant speed, from 5 to 8 sec it is at rest. From 8 to 12 sec, it is slowing down.

- B. Distance moved = Total area

$$S_T = \frac{1}{2} (5) (20) + (3) (20) + \frac{1}{2} (5) (20) \\ = 160\text{m}$$

$$C. v_1 = \frac{\Delta S_1}{\Delta t_1} = \frac{20 - 0}{5} = 4\text{m/s},$$

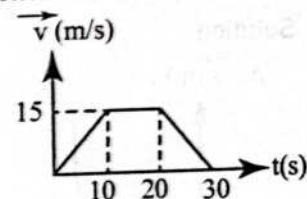
$$v_2 = \frac{\Delta S_2}{\Delta t_2} = 0$$

$$v_3 = \frac{\Delta S_3}{\Delta t_3} = \frac{0 - 20}{4} = -5\text{m/s}$$

- D. Displacement = $\Delta S_1 + \Delta S_2 + \Delta S_3 = (20 - 0) + (20 - 20) + (0 - 20)$
 $\Delta S = 0$, zero. The car returned to its starting point.

72. If the velocity - time graph of a body is plotted as follows;

- Describe the nature of its motion
- Calculate acceleration of the body
- Find distance covered by the body
- What is the displacement of the body



Solution

- A. From 0 to 10 sec, the body is speeding up, accelerating at 1.5m/s^2 . From 10 sec to 20 sec, the body is moving at a constant velocity of 15m/s , zero acceleration. From 20 sec to 30 sec, the body is slowing down, decelerating at 1.5m/s^2 , until it comes to rest.

$$B. a_1 = \frac{\Delta V_1}{\Delta t_1} = \frac{15 - 0}{10 - 0} = 1.5\text{m/s}^2$$

$$a_2 = \frac{\Delta V_2}{\Delta t_2} = \frac{15 - 15}{20 - 10} = 0, \text{ zero}$$

$$a_3 = \frac{\Delta V_3}{\Delta t_3} = \frac{0 - 15}{30 - 20} = -1.5\text{m/s}^2$$

$$C. S_T = S_1 + S_2 + S_3 = \frac{1}{2} (10)(15) + (15)(10) + \frac{1}{2} (10)(15) \\ = 300\text{m}$$

$$D. \Delta S = (V_{av_1}) (\Delta t_1) + (V_{av_2}) (\Delta t_2) + (V_{av_3}) (\Delta t_3) \\ \Delta S = \left(\frac{0+15}{2} \right) 10 + \left(\frac{15+15}{2} \right) 10 + \left(\frac{15+0}{2} \right) 10 \\ = 300\text{m}$$

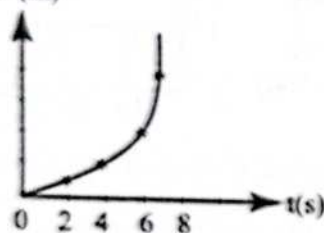
73. If a body has the following journey history, answer the following questions.

128	72	32	8	0	$\vec{s}(m)$
8	6	4	2	0	$t(s)$

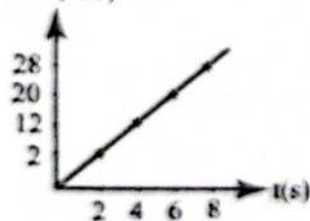
- Plot the displacement - time graph
- Plot the velocity - time graph
- Plot the acceleration - time graph
- Is the body in uniform motion or a uniform acceleration

Solution

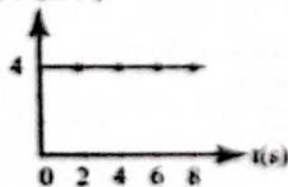
A. $\vec{s}(m)$



B. $\vec{v}(m/s)$



C. $\vec{a}(m/s^2)$



$$V_1 = \frac{\Delta s_1}{\Delta t_1} = \frac{8-0}{2-0} = 4m/s$$

$$V_2 = \frac{\Delta s_2}{\Delta t_2} = \frac{32-8}{4-2} = 12m/s$$

$$V_3 = \frac{\Delta s_3}{\Delta t_3} = \frac{72-32}{6-4} = 20m/s$$

$$V_4 = \frac{\Delta s_4}{\Delta t_4} = \frac{128-72}{8-6} = 28m/s$$

$$a_1 = \frac{\Delta v_1}{\Delta t_1} = \frac{12-4}{4-2} = 4m/s^2$$

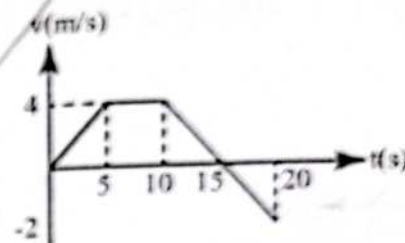
$$a_2 = \frac{\Delta v_2}{\Delta t_2} = \frac{20-12}{6-4} = 4m/s^2$$

$$a_3 = \frac{\Delta v_3}{\Delta t_3} = \frac{28-20}{8-6} = 4m/s^2$$

D. The body is moving at constant acceleration of $4m/s^2$ starting from rest.

74. The velocity - time graph of a truck is given as follows. Calculate:

- Distance moved
- Displacement of the truck



Solution

A. Distance travelled = Total area under the curve

$$S_T = \frac{1}{2}(5)(4) + \frac{1}{2}(5)(2) + \frac{1}{2}(5)(2)$$

$$= 45m$$

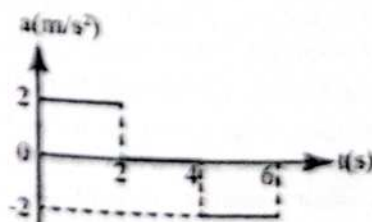
B. Displacement = $\Delta S_1 + \Delta S_2 + \Delta S_3 + \Delta S_4$

$$\Delta S = (V_{av_1}) \Delta t_1 + (V_{av_2}) \Delta t_2 + (V_{av_3}) \Delta t_3 + (V_{av_4}) \Delta t_4$$

$$\Delta S = \left(\frac{4+0}{2}\right)5 + \left(\frac{4+4}{2}\right)5 + \left(\frac{0+4}{2}\right)5 + \left(\frac{0+(-2)}{2}\right)5$$

$$\Delta S = 35m$$

75. If the acceleration - time graph for a car starting from rest looks the following



A. Calculate its velocity at each interval

B. Draw the velocity - time graph.

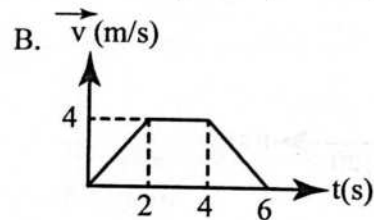
Solution

A. From 0 to 2 Sec, $\Delta V_1 = a \Delta t_1 = (2)(2) = 4\text{m/s}$

From 2 to 4 Sec, $\Delta V_2 = a \Delta t_2 = 0$, zero

From 4 to 6 sec, $\Delta V_3 = a \Delta t_3 = -4\text{m/s}$

That is at $t=2\text{ sec}$, $V=4\text{m/s}$, at $t=4\text{ sec}$, $V=4\text{m/s}$, at $t=6\text{ sec}$, $V=0$, zero



3.5 Relative Velocity in One Dimension

The motion of a body is relative. It depends on the frame of reference from which it is observed.

Relative Velocity: Is the rate at which a body changes its position with respect to another reference point.

For example, when you are moving in a car, for an observer standing by the road, you are moving at the speed of the car, but, for an observer who sit next to you in the car, you are not moving at all. Therefore, a body that seems to move with respect to one reference frame may not be moving at all as seen from another frame of reference.

The relative velocity between two bodies is obtained by taking the difference of their velocities. That is, if body A is moving at velocity V_A and body B at velocity V_B with respect to say the ground, their relative velocities are

$V_{AB} = V_A - V_B$, velocity of body A with respect to body B

$V_{BA} = V_B - V_A$, velocity of body B with respect to body A

- ☑ When calculating the relative velocity of a body, we need to consider direction of motion of the bodies, and when two bodies are moving perpendicularly, then, their relative velocity is obtained using Pythagoras's theorem.

Illustrative Examples

76. Two cars A and B are moving at velocities of $V_A = 30\text{m/s}$ and $V_B = 40\text{m/s}$. What will be their relative velocity if they are moving

A. In the same direction

B. In opposite direction

C. At right angle to each other

Solution

A. $V_{AB} = V_A - V_B = 30 - 40 = -10\text{m/s} = 10\text{m/s}$, left. The minus sign indicates that, for an observer in car B, car A seems to move backward.

$V_{AB} = V_B - V_A = 40 - 30 = 10\text{m/s}$, right

B. $V_{AB} = V_{BA} = V_A - (-V_B) = V_A + V_B = 30 + 40 = 70\text{m/s}$

C. $V_{AB} = V_{BA} = V_{AB}$

$$= V_{BA} = \sqrt{V_A^2 + V_B^2} = \sqrt{(30)^2 + (40)^2} = 50\text{m/s}$$

77. The position of a car that accelerates uniformly starting from rest is given below.

$t \text{ (s)}$	0	1	2	3
$s \text{ (m)}$	0	2	8	X

What is the distance covered by the car in $t = 3$ seconds?

Solution

$$S = ut + \frac{1}{2}at^2, u = 0, \text{ at } t = 2\text{ sec}, (S) = 8\text{m}$$

$$8 = 0 + \frac{1}{2}(a)(2)^2 \Rightarrow a = 4\text{m/s}^2$$

$$\text{Hence, at } t = 3\text{ sec}, S = ut + \frac{1}{2}at^2 = 0 + \frac{1}{2}(4)(3)^2 = 18\text{m}$$

78. If the position of a body with time looks the following

$x \text{ (m)}$	5	15	25	35	45	55
$t \text{ (s)}$	0	5	10	15	20	25

relat x and t

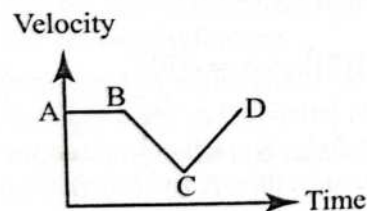
Solution

$$x = 2t + 5$$

End of unit Questions and problems

I. Give Short Answer to The Following Questions

- When do we say body a is in motion?
- What is distance covered by a body?
- What is displacement of a body?
- Explain the difference between speed and velocity?
- Explain the difference between average speed and average velocity
- What is instantaneous velocity of a body?
- What is acceleration?
- What do we mean by uniform motion?
- Is there any difference between uniform motion and uniformly accelerated motion? Explain
- What is Free Fall? Explain
- If a velocity - time graph became horizontal, what will happen to the acceleration of the body.
- Explain what relative velocity mean
- What dose the area of velocity - time graph represent?
- When will acceleration a body became negative.
- Based on the given velocity - time graph, explain the nature of motion of the body.



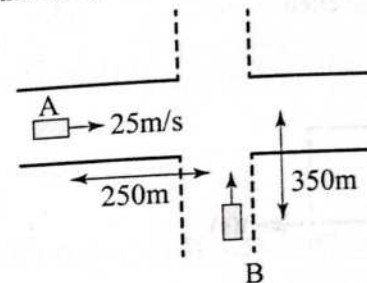
Solve the Following Problems

- If you are running at 6m/s and decelerate at 2m/s^2 ,
 - How long will it take you to stop?
 - How far will you go?
- A uniformly moving train covered a 24 km in 10 minutes . How far will

it travel in 1hr and 30 minutes ?

- Two soccer players are approaching each other, each with a speed of 8m/s when they are 48m apart. How much time passes before they collide?

- Two cars heading to a cross road with uniform velocities. If they collide at the center of the road, what must be the speed of car B?



- The distance of a body is expressed by the relation; $S = 2t^2 + t + 10$. What is its average speed during the first 10 seconds of its motion?
- A body with an initial speed of 1 m/s accelerates uniformly at 2m/s^2 . What distance does it cover in the third second?
- An auto mobile driver moving at 20m/s spotted a truck 50m ahead that is moving at 10m/s . How long will it take him to overtake the truck?
- A car speeds up from 5m/s to 25m/s in 10sec . What is its acceleration?
- A body initially at rest accelerates uniformly at 2m/s^2 . How long will it take him to cover 400m ?
- A body accelerates at 3m/s while its velocity changes from 20m/s to 40m/s . What is the distance covered by the body?
- A car starts from rest and accelerates uniformly at 2m/s^2 in a straight line
 - What is its speed after 5 seconds
 - How far will it travel in 10 seconds
 - How long will it take the car to cover 400m
- A body kicks a ball upwards with an initial speed of 10m/s . What is the ball's
 - Maximum height
 - Time of flight
- What is the relative velocity of a car moving at 40m/s due east with

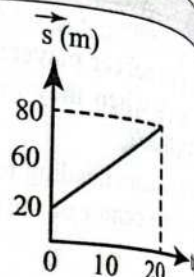
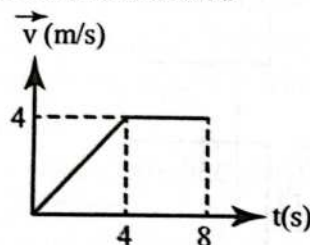
respect to itself

29. From the displacement - time graph shown, find the velocity of the body

30. From the velocity - time graph. Find

A. Acceleration of the body

B. Total distance travelled



II. Explanation to the Questions

- When it changes position with time
- Distance is the total path length travelled by a body
- Displacement is the change in position of a body in a certain direction
- Speed is distance per unit time, while velocity is displacement per unit time.
- Average speed is total distance divided by total time taken while average velocity is displacement per unit time.
- Instantaneous velocity is the velocity of the body at a specific instant of time or position
- Acceleration is the rate of change of velocity
- Uniform motion is motion of a body at constant speed
- Yes. In uniform motion acceleration is zero.
- Free Fall is a body that is dropped or thrown in to the air in any direction so that the only force acting on it is gravity
- Velocity is constant and acceleration is zero
- Relative velocity is the velocity of a body with respect to different frame of references.
- Displacement
- When the body slows down

15. From A to B, moved at constant speed, B to C, it slows down and from C to D it speeds up.

II. Solution for the problems

$$16. A. t = \frac{v - u}{a} = \frac{0 - 6}{-2} = 3 \text{ sec}$$

$$B. S = ut - \frac{1}{2}at^2 = (6)(3) - \frac{1}{2}(2)(3)^2 = 9 \text{ m}$$

$$17. V = \frac{S_1}{t_1} = \frac{24}{0.166} = 144.5 \text{ km/h}$$

$$V = \frac{S_2}{t_2} \Rightarrow S_2 = (V_2)(t_2) = (144.5)(1.5) = 216 \text{ km}$$

18. Since they are approaching, their relative velocity is

$$V = \frac{s}{t} \Rightarrow t = \frac{s}{v} = \frac{48}{16} = 3 \text{ sec}$$

$$19. V_A = \frac{S_A}{t_A} \Rightarrow t_A = \frac{S_A}{V_A} = \frac{250}{25} = 10 \text{ sec}$$

$$V_B = \frac{S_B}{t_B} = \frac{350}{10} = 35 \text{ m/s}$$

$$20. V_{av} = \frac{S_T}{t_T} = \frac{2t^2 + t + 10}{10} = \frac{2(10)^2 + 10 + 10}{10} = 22 \text{ m/s}$$

$$21. S_n^u = u + \frac{a}{2}(2t-1) = 1 + \frac{2}{2}(2(3)-1) = 6 \text{ m}$$

$$22. S_A = S_t + 50 \Rightarrow V_A t = V_t t + 50$$

$$(20 - 10)t = 50 \Rightarrow t = 5 \text{ sec}$$

$$23. a = \frac{v - u}{t} = \frac{25 - 5}{10} = 2 \text{ m/s}^2$$

$$24. S = ut + \frac{1}{2}at^2 \Rightarrow t^2 = \frac{2(S)}{a} = \frac{2(400)}{2} \Rightarrow t = 20 \text{ sec}$$

$$25. V^2 = u^2 + 2as \Rightarrow S = \frac{V^2 - u^2}{2a} = \frac{(40)^2 - (20)^2}{2(3)} = 200\text{m}$$

$$26. A. V = u + at = (5)2 = 10\text{m/s}$$

$$B. S = ut + \frac{1}{2}at^2 = \frac{1}{2}(2)(10)^2 = 100\text{m}$$

$$C. S = ut + \frac{1}{2}at^2 \Rightarrow t = \sqrt{\frac{2(S)}{a}} = \sqrt{\frac{2(400)}{2}}$$

$$t = 20 \text{ Seconds}$$

$$27. A. V^2 = u^2 - 2gh_{\max}, V = 0$$

$$h_{\max} = \frac{V_2}{2g} = \frac{(10)^2}{2(10)} = 5\text{m}$$

$$B. h = ut - \frac{1}{2}gt^2, h = 0$$

$$t = \frac{2u}{g} = \frac{2(10)}{10} = 2\text{sec}$$

$$28. V_A = V_A - V_A = 40 - 40 = 0, \text{ zero}$$

$$29. V = \text{slope} = \frac{\text{Rise}}{\text{Run}} = \frac{\Delta H}{\Delta x} = \frac{\Delta S}{\Delta t} = \frac{80 - 20}{20 - 0} = 2\text{m/s}$$

$$30. A. a_1 = \frac{\Delta V_1}{\Delta t_1} = \frac{4 - 0}{4} = 1\text{m/s}^2, a_2 = \frac{\Delta V_2}{\Delta t_2} = \frac{4 - 4}{4} = 0, \text{ zero}$$

$$B. S_T = \frac{1}{2}(4)(4) + (4)(4) = 24\text{m}$$

UNIT -4

4. Force, Work, Energy and Power

4.1 The Concept of Force

4.2 Newton's Laws of Motion

4.3 Force of Friction

4.4 The Concept of Work

4.5 Mechanical Energy

4.6 Mechanical Power

4. Force, Work, Energy and Power

Dear learner, how are you? This unit provides you the most common terms we use in our every day life. So now you will not only be able to define the concepts, force, work, energy and power, but also explain the variations and relations among them. Have a nice time.

4.1 What is Force

In our everyday life, we use the terms force, energy and power interchangeable as if they mean the same thing. In physics however, they are distinct terms with different meanings as we define them in the coming sessions.

Force: Is a pull or a push interaction between bodies

Force is a vector quantity and its SI unit is the newton (N), and the instrument used to measure force is called **newton meter**, which can be digital or analogue.

What are types of Forces

The interaction between bodies may involve physical contact or may be at distant. Therefore, a force can be contact or non - contact.

Contact force: Is a force for which the interacting bodies are in touch with each other.

Examples include, a body kicking a ball, a man pushing a cart, a girl carrying a bag.



kicking ball



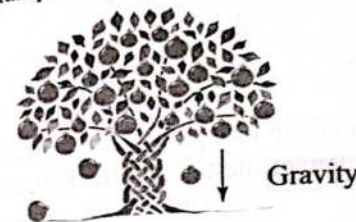
pushing a cart



carrying a bag

Non - Contact Force: Is a force that can act at a distance without the need of physical contact between the interacting bodies.

Examples include, gravity, magnetic force and electro static force



magnetic force



electro static force

Effects of Force

When a force acts on a body, it may deform or change the state of motion of the body.

Therefore, a force may cause a body to:

- Change its size and shape
- Start motion
- Stop motion
- Change its direction of motion

Conceptual Example

1. Can a force always cause motion? Explain

Explanation

No! it is a net force that causes motion

2. What is needed to make an object change its motion?

Explanation

A force is needed to change motion speeding up, slowing down, turning, and speeding all are motion changes that need a force.

4.2 Newton's Laws of Motion

The three laws of motion formulated by Isaac Newton are stated as follows:

Newton's First Law → The law of Inertia

This law is valid for a body that do not experience net external force.

Newton's 1st law states that;

"A body at rest remains at rest and a body in motion continues its motion at constant speed in a straight line as long as no net force acts it"

Did You Know?

Inertia is natural tendency of a body to remain in its existing state of motion and that is why we call the first law, the law of inertia and, the bigger the mass of a body, the larger its inertia.

Conceptual Example

3. How is inertia of a body related to the mass of the body? Explain?

Explanation

Because, mass is the measure of amount of matter contained in a body. Hence lighter bodies such as small plastic balls have few particles and can easily be stopped or moved. But, heavier bodies such as a big rock have much particles and can not be easily stopped or moved.

4. What will happen to your body if the car you are in suddenly

- A) Starts motion
- B) Stops motion
- C) Change its direction of motion

Explanation

- A) Your body will lean backward since it wants to remain at rest
- B) Your body will be thrown forward since you body wants to keep moving at the car's speed
- C) Your body will be thrown side ways since it want to move at constant speed in a straight line

Newton's Second Law → The law of Acceleration

When no net force acts on a body, the body remains at rest or move at constant velocity. But, when a net force acts on it, the body accelerates and this is explained by the second law of newton

Newton's 2nd Law States that;

"The acceleration (a) produced on a body is directly proportional to the applied net force (F) and inversely proportional to the mass (m) of the body".

Mathematically, Newton's 2nd law is expressed as

$$\vec{F} = m\vec{a}$$

Therefore, $1\text{N} = 1\text{kg m/s}^2$

- One newton is the force that when acts on a body of mass 1kg produces an acceleration of 1m/s^2

Conceptual Example

5. What is needed to give an object a greater acceleration?

Answer: A larger force cause a larger acceleration.

6. What will happen to the acceleration of a body.

- A) Keeping the mass constant, the net force acting is doubled
- B) Keeping the net force constant, the mass is doubled

Explanation

- A) From, $F = ma \Rightarrow a = \frac{F}{m}$

$$a_1 = \frac{F_1}{m_1}$$

$$a_2 = \frac{F_2}{m_2} = \frac{2F_1}{m_1} = 2a, \text{ it is doubled.}$$

- B) Again, from $a = \frac{F}{m}$

$$a_1 = \frac{F_1}{m_1}$$

$$a_2 = \frac{F_2}{m_2} = \frac{F_1}{2m_1} = \frac{1}{2} a_1, \text{ it is halved}$$

7. Is there any difference between mass and weight of a body? Explain

Explanation

Yes there is Mass is the measure of the amount of matter contained by a body and it is a scalar quantity that is constant every where. But, weight is the gravitational force acting on a body towards the center of the earth and it is a vector quantity that varies from place to place.

Illustrative Examples

8. What a net force will cause a 10kg body to increase its velocity from 8m/s to 20 m/s in 3 seconds.

Solution

$$F = ma = m \left(\frac{v - u}{t} \right) = 10 \left(\frac{20 - 8}{3} \right) = 40\text{N}$$

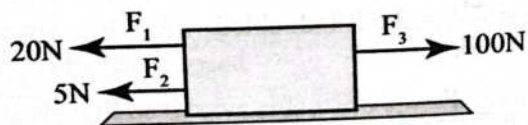
9. A force of 100N acts on a 25kg body that is initially at rest. At what time will the body attain a velocity of 20m/s?

Solution

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{100}{25} = 4\text{m/s}^2$$

$$a = \frac{v - u}{t} \Rightarrow t = \frac{v - u}{a} = \frac{20 - 0}{4} = 5\text{seconds}$$

10. If a block of mass 25kg resting on a smooth horizontal surface is subjected to the external forces shown. What acceleration will it experience?



Solution

$$F = ma \Rightarrow a = \frac{F}{m} = \frac{F_3 - (F_1 + F_2)}{m} = \frac{100 - (20 + 5)}{25} = 3\text{m/s}^2$$

11. The engine of a car produces an acceleration of 6m/s^2 in the car. If this

car pulls another car of the same mass, what would be its acceleration?

Solution

$$F_1 = F_2 \Rightarrow m_1 a_1 = m_2 a_2$$

$$a_2 = \frac{m_1 a_1}{m_2} = \frac{m_1 a_1}{2m_1} = \frac{a_1}{2} = \frac{6}{2} = 3\text{m/s}^2$$

12. Two carts are pulled by a child on a smooth surface. What is the force exerted on the string by cart B?



Solution

$$\text{For cart A: } F - T = m_A a \dots\dots\dots (1)$$

$$\text{For cart B: } T = m_B a \dots\dots\dots (2)$$

$$\text{From the equations; } a = \frac{F}{m_A + m_B} = \frac{20}{3 + 1} = 5\text{m/s}^2$$

$$\Rightarrow T = m_B a = (3)(5) = 15\text{N}$$

13. Which Combination of fundamental quantities can be used to express force?

- A) Acceleration and mass
B) Mass, time and velocity
C) Acceleration, Length and time
D) Time, length, mass

$$\text{Hint: From, } F = ma \Rightarrow 1\text{N} = 1\text{kg m/s}^2 = \frac{\text{ML}}{\text{T}^2}$$

Answer: D

14. Two children are fighting over a toy. One pulls on it with a force of 75N East, the other pulls with a force of 65N west. What is the net force on the toy?

- A) 140N East B) 140N West C) 10N East D) 10N West
- Hint: $F = F_{\text{East}} - F_{\text{West}} = 75 - 65 = 10\text{N East}$

Answer: C

15. "You cannot push a table without it pushes back on you" which of the physics laws describes this statement.

- A) Newton's first law C) Newton's third law
B) Newton's second law D) Kepler's third law

Hint: This is the law of action and reaction

Answer: C

16. What happens to a body on which a constant net force acts?

- A) It velocity increases constantly
B) Its acceleration increases constantly
C) It moves with constant velocity
D) Its acceleration becomes opposite to the force

Hint: A constant net force give the body a constant acceleration and which in turn cause the velocity of the body to increase at a constant rate

Answer: A

Newton's Third law → The law of Action and Reaction

The existence of force in pairs is explained by the third law of Newton as follows

Newton's 3rd law states that;

"For every action, there is an equal and opposite reaction"

That is, if body 1 exerts an action force on body 2, then body 2 exerts an equal but opposite reaction force on body 1

Mathematically, this can be expressed as;

$$F_{12} = -F_{21}$$

Where: F_{12} = Force exerted by body 1 on body 2

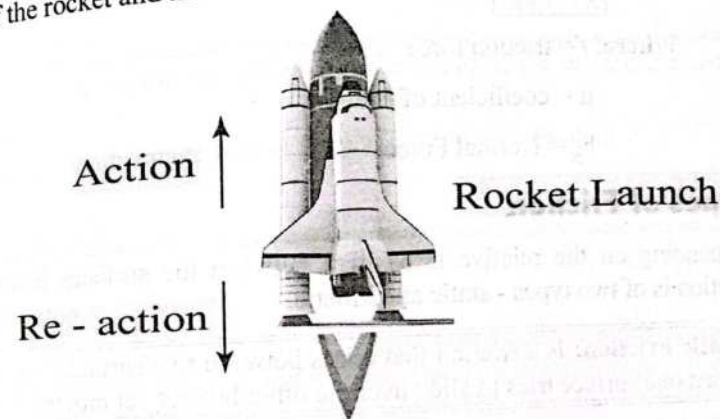
F_{21} = Force exerted by body 2 on body 1

(-) = The force act in opposite direction

→ The action and reaction forces act on two different bodies.

As an example, consider the following situations;

In a rocket launch, the fuel is burnt and the resulting hot gases are forced out of the rocket and the reaction force drives the rocket forward



Conceptual Example

17. A boy kicks a ball with a force of 400N due east. What is the magnitude and direction of the reaction force of the ball.

Explanation

If the action force is the force of the boy on the ball, then the reaction force became the force of the ball on the boy. Therefore, the reaction force magnitude is 400N and its direction is due west.

4.3 What is Friction Force?

When one surface tries to slide over another surface, there is resistance to motion by the other surface, this resistance to motion is called *friction force*

Friction: Is a force that opposes then relative motion of surfaces that are in contact.

The force of friction depends on:

→ The nature of the surfaces in contact. That is the roughness or smoothness of the surfaces, which is expressed using the coefficient of

friction, μ (μ)

- The normal force (F_N), which is the pressing or supporting force perpendicular to the surfaces in contact.

Mathematically, friction force is calculated using

$$f = \mu F_N$$

Where: f = friction force

μ = coefficient of friction

F_N = Normal Force

Types of Friction

Depending on the relative movement between the surfaces in contact, friction is of two types - static and kinetic.

Static Friction: Is a friction that arises between two surfaces in contact when one surface tries to slide over the other but not yet moving.

Mathematically, it is obtained by;

$$f_s = \mu_s F_N$$

Where: The subscript (s) stands for static

- The maximum static friction that arises on the verge of motion is called **static friction**.

Kinetic Friction: Is a friction force between two surface that are in relative motion with each other.

Mathematically, it is obtained by;

$$f_k = \mu_k F_N$$

Where: The subscript (k) stands for kinetic.

- Static friction is usually greater than kinetic friction.

That is, $f_s > f_k$

$$\mu_s F_N > \mu_k F_N$$

$$\Rightarrow \mu_s > \mu_k$$

- Coefficient of static friction is greater than the coefficient of kinetic friction.

Conceptual Examples

18. Why do vehicles, easily get stuck in a mud? Explain

Explanation

Because, the friction force between the tires and the ground surface is reduce.

19. Is there any advantage we get from friction force? Explain

Explanation

Yes. Friction helps us to walk, to write and it also help cars to move and to stop.

20. Friction causes shoes, cloths, car tires and parts of machinery to wear out and it retards motion, produces noise and causes wastage of energy. What should we do to reduce such negative effects of friction?

Explanation

We need to lubricate, smoothen and polish surfaces and use rolling instead of sliding motion.

Illustrative Examples

21. A 5kg block is at rest on a horizontal table. If the static and kinetic coefficient of friction between the surfaces in contact are $\mu_s = 0.75$ and $\mu_k = 0.45$. What force is needed to

A) Start the block move

B) Keep the

$$C) f_s = \mu_s F_N = (0.75) (mg) = (0.75) (10) (5) = 37.5N$$

$$D) f_k = \mu_k F_N = (0.45) (mg) = (0.45) (10) (5) = 22.5N$$

22. A block slides down a 37° incline plane with a constant velocity. What is the coefficient of friction between the surfaces?

Solution

$$F - f - ma = 0 \Rightarrow m g \sin \theta - \mu m g \cos \theta = 0$$

$$\mu = \sin \theta / \cos \theta = 0.6 / 0.8 = 0.75$$

4.4 What is work?

In every day language, work is any activity that requires physical or mental effort to be accomplished. In physics however, work is a technical term and is defined as follows:

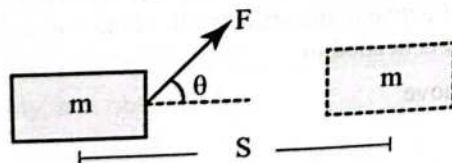
Work: Is a transfer of energy from one body to the other and obtained by to the product of a force and a displacement.

Work is a scalar quantity and its SI unit is the Joule (J)

In physics, work to be done, the conditions are:

- Force must be exerted
- The body must be displaced, and
- The orientation between the force and the displacement must be considered.

Mathematically, the work done on a body can be computed as follows:
If a body of mass m is moved a distance S by the application of external force F that makes an angle θ with the displacement, as shown.



Then, work = (Force) (Displacement in the force direction)

$$W = F S \cos \theta$$

$$1 \text{ J} = 1 \text{ Nm}$$

- One joule of work is done when 1 Newton of force moves a body a displacement of 1 meter in the direction.

Conceptual Examples

23. What will be the nature of the work done when the angle between the force and the displacement is

- A) $\theta < 90^\circ$
- B) $\theta = 90^\circ$
- C) $\theta > 90^\circ$

Explanation

We know, $W = F s \cos \theta$

A) $\theta < 90^\circ$, $\cos \theta$ is positive $\Rightarrow W = + \text{ve}$, positive

B) $\theta = 90^\circ$, $\cos \theta$ is zero $\Rightarrow W = 0$, zero

C) $\theta > 90^\circ$, $\cos \theta$ is negative $\Rightarrow W = - \text{ve}$, negative

24. What is the work done by gravitational force on a satellite orbiting the earth, Explain

Explanation

In this case, the force and displacement are perpendicular and hence, the work done is zero.

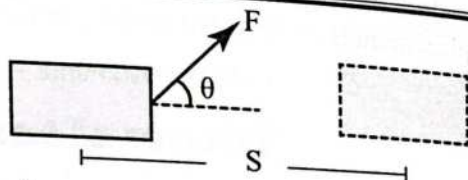
25. Suppose you lifted a load from the ground and carried it then you walked for some distance on a horizontal level road at constant velocity. Is there any work you did on the load?

Explanation

Yes. You did some work when you were lifting the load up.

Illustrative Examples

26. A man pulled a box by a force of 200N with a rope that makes an angle of 60° from the horizontal. What is the work done by the man if he displaced the box 100m along the horizontal?

Solution

$$W = F \cos \theta$$

$$= (200)(100)(\cos 60^\circ) = (20,000) \left(\frac{1}{2}\right) = 10,000 \text{ J}$$

27. When a force of 150N acts on a body that is at rest, its velocity became 10 m/s in 5 seconds. What is the work done by the force?

Solution

$$W = F \cos \theta = F \left(\frac{v + u}{2} \right) t = 150 \left(\frac{10 + 0}{2} \right) 5 = 3750 \text{ J}$$

$$\text{Note: } \theta = 0^\circ, \cos 0^\circ = 1$$

$$\text{and, } S = \left(\frac{u + v}{2} \right) t$$

28. A block is dragged a distance of 10m by a rope under a constant force of 120N. If a 720J of work is done by the force, what angle does the rope make with the ground?

Solution

$$W = F \cos \theta \Rightarrow \cos \theta = \frac{W}{Fs} = \frac{720}{(120)(10)} = 0.6$$

$$\theta = \cos^{-1}(0.6) = 53^\circ$$

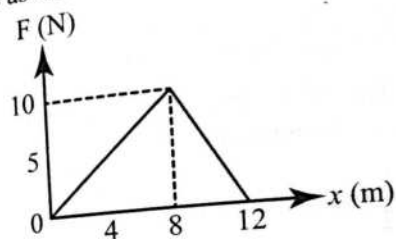
29. What is the work done by a crane that lifted 1000 boxes each with 25 kg to a height of 10m

Solution

$$W = F s \cos \theta = mgh = 1000(25)(10)(10)$$

$$= 2500000 \text{ J}$$

30. A force varies with the displacement as shown below. What is the work done by this force as the body is displaced from $x = 0$ to $x = 12 \text{ m}$

*Solution*

Work done = Area under the $\vec{F} - x$ graph

$$\frac{1}{2} bh$$

$$W = \frac{1}{2} (10)(12) = 60 \text{ J}$$

31. How much work is done by a 65kg runner on himself to accelerate from rest to 10m/s?

Solution

We know, $W = F \cos \theta$, if $\theta = 0^\circ$, $\cos 0^\circ = 1$

$$W = FS = (ma)S, \text{ but } v^2 = u^2 + 2as$$

$$W = \frac{1}{2} mv^2 - \frac{1}{2} mu^2, u = 0$$

$$W = \frac{1}{2} mv^2 = \frac{1}{2} (65)(10)^2 = 3250 \text{ J}$$

4.5 What is Mechanical Energy?

A body that has energy can do work, and a work done on a body can be stored as an energy by the body.

Energy: Is the capacity or ability to do work.

Energy is scalar quantity and its SI unit is the joule (J)
 ➤ Regardless of its difference forms, energy is always either kinetic or potential.

Kinetic Energy: Is the energy possessed by a body because of its motion

Kinetic energy of a body depends on the mass (m) and the speed (v) of the body, and mathematically, it is obtained by;

$$\text{Kinetic Energy} = \frac{1}{2} (\text{mass}) (\text{speed})^2$$



Conceptual Examples

32. Can the kinetic energy of a body ever be negative? Explain

Explanation

No! Since kinetic energy of a body is expressed as a product of its mass and its speed squared, both non-negatives, it can never be negative.

33. What will happen to the kinetic energy of a body if for

- A) Fixed speed, mass is doubled
- B) Fixed speed, mass is halved
- C) Fixed mass, speed is doubled
- D) Fixed mass, speed is halved

Explanation

$$\text{A) } KE_1 = \frac{1}{2} m_1 v^2$$

$$KE_2 = \frac{1}{2} (2m_1) v^2 = 2 \left(\frac{1}{2} m_1 v^2 \right)$$

$$KE_2 = 2KE_1, \text{ doubled}$$

$$\text{B) } KE_1 = \frac{1}{2} m_1 v^2$$

$$KE_2 = \frac{1}{2} \left(\frac{m_1}{2} \right) v^2 = \frac{1}{2} \left(\frac{1}{2} m_1 v^2 \right)$$

$$KE_2 = \frac{1}{2} KE_1, \text{ halved}$$

$$\text{C) } KE_1 = \frac{1}{2} m_1 v^2$$

$$KE_2 = \frac{1}{2} m (2v_1)^2 = 4 \left(\frac{1}{2} m_1 v^2 \right)$$

$$KE_2 = 4KE_1, \text{ Became four - times}$$

$$\text{D) } KE_1 = \frac{1}{2} KE_1$$

$$KE_2 = \frac{1}{2} m \left(\frac{1}{2} v_1 \right)^2 = \frac{1}{4} \left(\frac{1}{2} m_1 v^2 \right)$$

$$KE_2 = \frac{1}{4} KE_1, \text{ Became one - fourth}$$

Work - Energy Theorem

Since work done is energy transfer, this theorem says, if external force acts on a body, it will cause its kinetic energy to change.

Work - Energy Theorem States that; "The work done on a body is equal to the change in its kinetic energy".

This theorem can be expressed mathematically as follows:

We know, $W = F \cos \theta = Fs$, maximum

$$W = (ma) s$$

$$\text{And, from, } v^2 = u^2 + 2as \Rightarrow as = \frac{v^2 - u^2}{2}$$

$$W = m \left[\frac{v^2 - u^2}{2} \right]$$

$$W = \frac{1}{2} mv^2 - \frac{1}{2} mu^2$$

$$KE_f - KE_i$$

$$W = \Delta K_E$$

Illustrative Examples

34. A car of mass 400kg is traveling at a speed of 20m/s. What is the kinetic energy of the car?

Solution

$$K_E = \frac{1}{2} mv^2 = \frac{1}{2} (400) (20)^2$$

$$= 80,000J$$

35. An object of mass 100kg revolves around the earth with a kinetic energy of $2.45 \times 10^{10}J$. What is the speed of the object?

Solution

$$K_E = \frac{1}{2} mv^2 \Rightarrow v = \sqrt{\frac{2K_E}{m}}$$

$$V = \sqrt{\frac{2(2.45 \times 10^{10})}{1000}} = 7 \times 10^3 m/s$$

36. What is the work done by a force in accelerating a 10kg body from rest to a speed of 15m/s?

Solution

$$W = \Delta K_E = \frac{1}{2} mv^2 - \frac{1}{2} mu^2$$

$$W = \frac{1}{2} (10) (15)^2 - \frac{1}{2} (10) (0)$$

$$W = 1125J$$

37. A 100J of work accelerates a car from rest to 5m/s. How much work is

needed to accelerate the car from 5m/s to 15m/s

Solution

$$W_1 = \Delta K_{E1} = \frac{1}{2} mv_1^2 - \frac{1}{2} mu_1^2$$

$$m = \frac{2W}{V_1^2} = \frac{2(100)}{(5)^2} = 8kg$$

$$W_2 = \Delta K_{E2} = \frac{1}{2} m [v_2^2 - v_1^2]$$

$$W = \frac{1}{2} (8) [(15)^2 - (5)^2]$$

$$= 800J$$

38. If a 4kg body initially at rest travels a distance of 5m in 2seconds under the action of a constant force, what work is done on the body during this time?

Solution

$$W = \Delta KE = \frac{1}{2} mv^2 - \frac{1}{2} mu^2$$

$$u = 0, s = \left(\frac{v - u}{2} \right) t \Rightarrow v = \frac{2(s)}{t} = \frac{2(5)}{2} = 5m/s$$

$$W = \frac{1}{2} mv^2 - \frac{1}{2} mu^2 = \frac{1}{2} m [v^2 - u^2]$$

$$W = \frac{1}{2} (4) [(5)^2 - (0)^2]$$

$$W = 50J$$

39. What Average force is needed to stop a 100g bullet travelling at 300m/s as it penetrates in to wood a distance of 10 cm?

Solution

$$W = \Delta KE = \frac{1}{2} mv^2 - \frac{1}{2} mu^2, V = 0$$

$$fs = -\frac{1}{2} mu^2 \Rightarrow F = \frac{-mu^2}{2s}$$

$$W = m \left[\frac{v^2 - u^2}{2} \right]$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$KE_f - KE_i$$

$$W = \Delta K_E$$

Illustrative Examples

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Solution

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Solution

$$K_E = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2K_E}{m}}$$

$$V = \sqrt{\frac{2(2.45 \times 10^{10})}{1000}} = 7 \times 10^3 m/s$$

36. What is the work done by a force in accelerating a 10kg body from rest to a speed of 15m/s?

Solution

$$W = \Delta K_E = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$W = \frac{1}{2}(10)(15)^2 - \frac{1}{2}(10)(0)$$

$$W = 1125J$$

37. A 100J of work accelerates a car from rest to 5m/s. How much work is

needed to accelerate the car from 5m/s to 15m/s

Solution

$$W_1 = \Delta K_{E1} = \frac{1}{2}mv_1^2 - \frac{1}{2}mu_1^2$$

$$m = \frac{2W}{V_1^2} = \frac{2(100)}{(5)^2} = 8kg$$

$$W_2 = \Delta K_{E2} = \frac{1}{2}m[v_2^2 - v_1^2]$$

$$W = \frac{1}{2}(8)[(15)^2 - (5)^2]$$

$$= 800J$$

38. If a 4kg body initially at rest travels a distance of 5m in 2seconds under the action of a constant force, what work is done on the body during this time?

Solution

$$W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$u = 0, s = \left(\frac{v - u}{2} \right)t \Rightarrow v = \frac{2(s)}{t} = \frac{2(5)}{2} = 5m/s$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m[v^2 - u^2]$$

$$W = \frac{1}{2}(4)[(5)^2 - (0)^2]$$

$$W = 50J$$

39. What Average force is needed to stop a 100g bullet travelling at 300m/s as it penetrates in to wood a distance of 10 cm?

Solution

$$W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2, V = 0$$

$$fs = -\frac{1}{2}mu^2 \Rightarrow F = \frac{-mu^2}{2s}$$

$$F = \frac{-(0.1)(300)^2}{2(0.1)} = -45000\text{N}$$

The negative sign indicates the force is resistive force

40. The driver of a 2000kg car traveling at 20m/s applies the brakes of the car. If the brakes provide a frictional force of 4000N. What would be the stopping distance of the car?

Solution

$$W = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2, V = 0$$

$$-fs = -\frac{1}{2}mu^2 \Rightarrow s = \frac{mu^2}{2f}$$

$$S = \frac{(2000)(400)}{(2)(4000)} = 100\text{m}$$

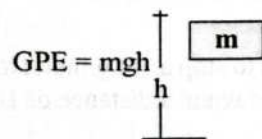
Potential Energy: Is the energy possessed by a body because of its position or configuration

Potential energy is of two types Gravitational and Elastic.

Gravitational Potential Energy: Is the energy stored by a body because of its position from some reference surface.

It depends on the height (h) and mass (m) of the body and is give by:

Gravitational potential Energy = (Mass)(height)(Acceleration due to gravity)



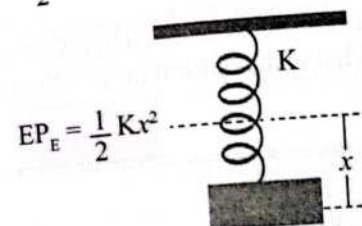
The heavier the mass and the higher the body is from the ground, the greater its gravitational potential energy.

Elastic Potential Energy: Is the energy stored by a body because of its configuration. That is, compression or extension of the body.

It depends on the force constant (K) and deformation (x) of the material

and is given by;

$$\text{Elastic potential} = \frac{1}{2} (\text{force constant}) (\text{Deformation})$$



- The larger the force constant and the greater the deformation the bigger the elastic potential energy stored.

Conceptual Example

41. If a ball is raised to the same height, once on the moon and the other time on the earth, in which case the ball will have greater gravitational potential energy?

Explanation

We know, $GPE = mgh$, since m and h are same, and since g is greater on the earth than it is on the moon, the ball has larger GPE on the earth.

42. If the deformation of a material is doubled, by what factor will its elastic potential energy change?

Explanation

$$EP_{E_1} = \frac{1}{2} Kx_1^2 \text{ and } EP_{E_2} = \frac{1}{2} Kx_2^2$$

But, $x_2 = 2x_1$ Hence

$$EP_{E_2} = \frac{1}{2} K(2x_1)^2 = 4 \left(\frac{1}{2} Kx_1^2 \right)$$

$$EP_{E_2} = 4EP_{E_1}$$

Illustrative Examples

43. A weight lifter raises a 200kg rock to a height of 2m. What is the increase in the potential energy of the rock?

Solution

$$\begin{aligned} \text{GPE} &= mgh = (200)(10)(2) \\ &= 4000\text{J} \end{aligned}$$

44. A spring of force constant 500N/m is compressed so that 0.625J of energy is stored in it. What is the deformation of the spring?

Solution

$$\begin{aligned} \text{EP}_E &= \frac{1}{2}kx^2 \Rightarrow x = \sqrt{\frac{1}{2}kx^2} \\ &= \sqrt{\frac{2(0.625)}{500}} = 0.05\text{m} \\ &= 5\text{cm} \end{aligned}$$

45. When a force of 120N is applied on a spring, it causes a stretch of 4cm. What potential energy is stored when it is compressed by 5cm?

Solution

$$\begin{aligned} \text{EP}_E &= \frac{1}{2}kx^2, \text{ but } F = kx \Rightarrow k = \frac{F}{x} = \frac{120}{0.04} = 3000 \frac{\text{N}}{\text{m}} \\ \Rightarrow \text{EPE} &= \frac{1}{2}(3000)(0.05)^2 = 3.75\text{J} \end{aligned}$$

- In the absence of dissipative force energy is conserved. And this is expressed by the conservation law.

Law of Conservation of Energy states that; "energy cannot be created or destroyed but it transferred from one form to the other"

That is for a closed system, the change in mechanical energy of body is zero.

$$\Delta \text{ME} = 0$$

$$\Rightarrow \text{ME}_{\text{initial}} = \text{ME}_{\text{final}}$$

$$\text{KE}_i + \text{PE}_i = \text{KE}_f + \text{PE}_f$$

Where : M_E = Mechanical Energy

P_E = Potential Energy

K_E = kinetic Energy

4.6 Mechanical Power

How fast work is done or energy is transformed is expressed using the concept of power.

Power: Is the rate at which work is done or energy is transferred from one form one from to the other.

Power is a scalar quantity and its SI unit is the watt (W)

Mathematically, power is obtained by

$$\text{Power} = \frac{\text{Work done}}{\text{Time Taken}} = \frac{\text{Energy Transferred}}{\text{Time Taken}}$$

$$P = \frac{W}{t}$$

$$\text{Hence, } 1\text{W} = \frac{1\text{J}}{\text{s}}$$

- One watt is the power developed when 1 Joule of work is done in 1 second

Conceptual Examples

46. Mr A and Mr. B are give the same work. If Mr A finished it in 2 hours and Mr. B in 3hours, who is more powerful? Explain

Explanation

Mr A is more powerful, since he finished the work in a shorter time.

47. Force one does 5J of work in 10s. Force two does 3J of work in 5s. Which force produces greater power?

Explanation

$$P_1 = \frac{W_1}{t_1} = \frac{5}{10} = 0.5W$$

$$P_2 = \frac{W_2}{t_2} = \frac{3}{5} = 0.6W$$

Force two produced more power.

Illustrative Examples

48. A kettle uses 180,000J of electrical energy in 3 minutes. What is the power of the kettle?

Solution

$$P = \frac{W}{t} = \frac{180,000}{3(60)}$$

$$P = 100W$$

49. A man lifts 50kg box to a height of 20m in 30 seconds. What is the power he developed?

Solution

$$P = \frac{mgh}{t} = \frac{(50)(10)(20)}{30}$$

$$P = 333W$$

50. A 1000kg car accelerates uniformly from 10m/s to 30m/s in 2 seconds. Calculate

A) The work done on the car

B) The power developed

Solution

$$A) W = \Delta K_E = \frac{1}{2}m[V^2 - u^2]$$

$$W = \frac{1}{2}(1000)[30^2 - 10^2] = 400,000J$$

$$B) P = \frac{W}{t} = \frac{400,000}{2}$$

$$P = 200,000W = 200KW$$

51. Show that the power developed by a body can be computed by;
 $P = Fv \cos \theta$

Where : F = net force magnitude
 v = speed of the body

Solution

$$\text{We know, } P = \frac{W}{t} = \frac{F \cos \theta}{t} = (F \cos \theta) \frac{s}{t}$$

$$P = Fv \cos \theta$$

52. A body is able to walk at a speed of 1.5 m/s pushing a bag along the horizontal with a force of 100N. What is the power he developed?

Solution

$$P = Fv \cos \theta$$

$$P = (100)(1.5) \cos (0^\circ) = 150W$$

53. A ball is kicked up in to the air. The work done by gravity and air resistance is respectively?

A) Positive, positive

C) Negative, negative

B) Positive, negative

D) Negative, Positive

Hint: The force are opposite to the direction of motion.

Answer: C

54. Which of the following is equivalent to 1J?

A) Kg m/s

B) Kg m/s²

C) Kg m²/s²

D) Kg m²/s²

Hint: 1J = 1Nm = 1kg m/s². m = kg m²/s²

Answer: C

55. A spring of force constant 160N/m lies on a friction less table. If a 12 kg block moving at 12 m/s strikes it, what will be the block speed when the spring is compressed by 1m?

A) 4m/s

B) 8m/s

C) 6m/s

D) 10m/s

$$\text{Hint: } \frac{1}{2} mu^2 = \frac{1}{2} mv^2 + \frac{1}{2} kx^2$$

$$\frac{1}{2} (12) (12)^2 = \frac{1}{2} (12) v^2 + \frac{1}{2} (160) (1)^2$$

$$v = 8 \text{ m/s}$$

56. How much work is done on a 0.5kg object to change its speed from 4m/s to 12 m/s

A) 4J

B) 8J

C) 16J

D) 32J

$$\text{Hint: } W = \frac{1}{2} mv^2 - \frac{1}{2} mu^2 = \frac{1}{2} (0.5) (12)^2 - \frac{1}{2} (0.5) (4)^2$$

$$W = 32J$$

Answer: D

57. A force does a negative work when

A) The force is perpendicular to the displacement

B) The force is opposite to the displacement

C) Both, force and displacement are positive

D) Both, force and displacement are negative

Hint: $W = Fs \cos \theta$, = Negative when $\theta = 180^\circ$

Answer: B

58. What is the average power generated by a 60kg man as he moved up stair 200m at an average speed of 15cm/s ?

A) 9000W

B) 900W

C) 90W

D) 9W

$$\text{Hint: } P = \frac{W}{t} = Fv = mgv$$

$$P = (60) (10) (0.15)$$

$$= 90W$$

Answer: C

59. The maximum work is done when the force and the displacement are

A) Parallel to each other

B) Perpendicular to each other

C) At 45° to each otherD) At 30° to each other

Hint: $W = Fs \cos \theta$

Answer: A

60. A 20kg body is displaced a height of 10m. The work done against gravity and the work done by gravity are respectively.

A) 2000J, 2000J

C) -2000J, 2000J

B) 2000J, -2000J

D) -2000J, -2000J

Hint: $W = mgh = (20) (10) (10) = 2000J$

Answer: B

61. If both the mass and the speed of a body are doubled, by what factor will the kinetic energy change?

A) 4

B) 2

C) 8

D) 6

$$\text{Hint: } KE_1 = \frac{1}{2} m_1 v_1^2$$

$$KE_2 = \frac{1}{2} m_2 v_2^2 = \frac{1}{2} (2m_1) (2v_1)^2$$

$$KE_2 = 8 (KE_1)$$

Answer: C

62. A 1kg block is released from rest along a rough inclined plane of 1m height. If the speed of the block at the bottom of plane is 4m/s, what is the work done by friction?

A) 10J

B) 8J

C) 2J

D) 4J

Hint: Work done by friction = $mgh - \frac{1}{2} mv^2$

$$W_f = (1) (10) (1) - \frac{1}{2} (1) (4)^2 = 2J$$

Answer: C

63. A 60kg man jumps down from a 0.8m high table. What will be his speed when he hits the ground?

A) 2m/s

B) 4m/s

C) 6m/s

D) 8m/s

$$\text{Hint: } \frac{1}{2} mv^2 = mgh \Rightarrow v = \sqrt{2gh} = \sqrt{2 (10) (0.8)} = 4 \text{ m/s}$$

End of unit Questions problems

Answer: B

I. Give short answers to the following questions.

1. What is force?
2. List the types of forces
3. Explain the effects of force
4. State the laws of motion
5. Explain the difference between mass and weight
6. What are the requirements for work to be done?
7. What is energy?
8. What is the difference between kinetic energy and potential energy?
9. What is power?
10. The unit of work is $\text{kg m}^2/\text{s}^2$. True or False ?
11. What is friction force?

II. Solve the following problems

12. What is the acceleration of a 10kg block when a force of 50N acts on it?
13. What force will let a 25kg object to accelerate at 4m/s^2 ?
14. What is the weight of a 250kg object on the moon where the acceleration due to gravity is 1.6m/s^2 ?
15. A box is displaced 6m by a 10N force along the horizontal. What is the work done?
16. A loader lifts a 500kg stone at a height of 8m in 2seconds. What is the power developed by the loader?
17. What is the kinetic energy of a 200g bullet fired at a speed of 300m/s ?
18. Calculate

- A) The potential energy of a 10kg stone at a height of 10m
- B) The position of the 10kg stone if it possesses a potential energy of 400

19. A crane is capable of doing $1.5 \times 10^5 \text{J}$ of work in 10 seconds. What is the power of the crane?

20. What is the driving force of a sport car of 400KW engine power so as to let it move at 40m/s

21. A 65kg bicyclist rides his 10kg cycle at 12m/s .

A) How much work must be done to stop the bicycle?

B) How far it travel if it takes 4seconds to stop it?

C) What is the magnitude of the stopping force?

22. A spring of 200N/m force constant is used to launch a 10g ball. If the spring is compressed by 5cm, calculate;

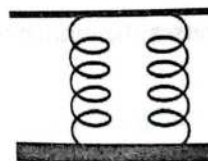
A) The energy stored in the spring

B) The velocity of the ball

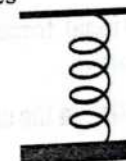
C) The height reached by the ball

23. If two springs with force constants K_1 and K_2 are connected in;

A) Parallel



B) Series



How much work is needed in each case, to stretch the system a distance x ?

I. Short Answers and Explanations

1. Force is a push or a pull interaction between bodies.
2. Force can be contact or non-contact
3. Force may cause deformation and change in the state of motion of a body
4. The laws of motion are formulated by newton and are the following.
 Newton's 1st law, the law of inertia
 Newton's 2nd law, the law of acceleration
 Newton's 3rd law, the law of action & reaction

5. Mass is the measure of amount of matter contained by a body and it is constant everywhere. Weight is the gravitational pull on a body and it varies from place to place. Weight and mass are related by, $W = mg$
6. In physics, work to be done; the necessary conditions are;
- Force must be exerted on the object
 - The object must be displaced in the force direction
 - The angle between the force and the displacement must be considered.
7. Energy is the capacity or the ability to do work
8. Kinetic energy is the energy of motion while, potential energy is the energy of position.
9. Power is the rate at which work is done or energy is transferred.
10. Work is defined as the product of force and displacement in the force direction.

$$W = F \cos \theta$$

$$1J = 1Nm = 1kg(m/s^2)m = 1kg m^2/s^2. \text{ True}$$

11. Frictional force is a force that opposes the motion of one surface over the other.

II. Solution to the end of unit problems.

$$12. F = ma \Rightarrow a = \frac{F}{m} = \frac{50}{10} = 5 m/s^2$$

$$13. F = ma = (25)(4) = 100N$$

$$14. W = mg = (250)(1.6) = 400N$$

$$15. W = F \cos \theta = (10)(6) \cos(0^\circ) = 60J$$

$$16. P = \frac{mgh}{t} = \frac{(500)(10)(8)}{2} = 20,000W = 20KW$$

$$17. K_E = \frac{1}{2}mv^2 = \frac{1}{2}(0.2)(300)^2 = 9000J$$

$$18. A) PE = mgh = (10)(10)(10) = 1000J$$

$$B) P_E = mgh \Rightarrow h = \frac{PE}{mg} = \frac{400}{(10)(10)} = 4m$$

$$19. P = \frac{W}{t} = \frac{1.5 \times 10^5}{10} = 1.5 \times 10^4 W$$

$$20. P = FV \Rightarrow F = \frac{P}{V} = \frac{400,000}{40} = 10,000N$$

$$21. A) W = \Delta KE = \frac{1}{2}m[v^2 - u^2], m = 65 + 10 = 75kg$$

$$W = \frac{1}{2}(75)[0^2 - 12^2] = 5400J$$

$$B) S = \left(\frac{v+u}{2}\right)t = \left(\frac{0+12}{2}\right)4 = 24m$$

$$C) f_s = W \Rightarrow f = \frac{W}{S} = \frac{5400}{24} = 225N$$

$$22. A) EP_E = \frac{1}{2}Kx^2 = \frac{1}{2}(200)(0.05)^2 = 0.25J$$

$$B) K_E = EP_E \Rightarrow \frac{1}{2}mv^2 = 0.25$$

$$v = 7 m/s$$

$$C) GPE = kE \Rightarrow mgh = 0.25$$

$$h = 2.5m$$

$$23. A) W = EPE = \frac{1}{2}KX^2$$

$$\text{For parallel springs, } K = K_1 + K_2$$

$$\Rightarrow W = \frac{1}{2}(K_1 + K_2)x^2$$

$$B) W = EPE = \frac{1}{2}Kx^2$$

$$\text{For series springs, } K = \frac{K_1 K_2}{K_1 + K_2}$$

$$\Rightarrow W = \frac{1}{2}\left(\frac{K_1 K_2}{K_1 + K_2}\right)x^2$$

UNIT 5

5. Simple Machines

5.1 Purpose of Simple Machines

5.2 Mechanical Advantage, Velocity Ratio and Efficiency of Simple Machines

5.3 Types of Simple Machines

5. What are Simple Machines?

Dear learner, how do you do? In this unit, you are going to, define simple machines, mention types of simple machines, describe the purpose of simple machines and get to know terms such as effort, load, mechanical advantage, velocity ratio, work input, work output, efficiency and so much more things. Enjoy!

5.1 Purpose of simple Machines

In our every day life, we use simple machines. But, you may ask, what are these machines any way?

Simple machine :- Is a device that helps us to do work more easily.

A **simple machine** is a machine that takes one force and changes its direction, distance, or strength. The force you apply to a machine is called the **effort**. These machines help us to get a job done easily, by multiplying force, multiplying speed or distance and by changing the direction of a force.

No matter what the type of simple machine may be, it will serve as one of the following purposes.

Force multiplier:- Enables us to move a big load using a small force.

Speed or Distance multiplier:- Enables us to move a load greater distance in a short time.

Direction changer:- Enables us to move a load in opposite direction to the applied force.

Now, let's be familiar with the terms we may face frequently in this unit.

Effort (E):- Is the input force that is exerted on the simple machine.

Load (L):- Is the output force that is exerted by the simple machine on the object.

Work Input (Win):- Is the work done on the machine by the effort.

Work output (Wout):- Is the work done by the machine on the object.

5.2 Mechanical Advantage, velocity ratio and Efficiency of simple machines

Here, under, we are going to be clear about the concepts mechanical advantage, velocity ratio and efficiency of simple machines.

Mechanical advantage:- Is the ratio of Load to Effort.

$$\text{Mechanical Advantage} = \frac{\text{load}}{\text{Effort}}$$

$$\boxed{MA = \frac{L}{E}}$$

→ It is a unit less quantity.

Mechanical Advantage is of two types ; Actual and Ideal

Actual Mechanical Advantage:- Is the ratio of load to effort taking account energy loss.

$$\boxed{AMA = \frac{L}{E}}, \text{ There is friction}$$

Ideal Mechanical Advantage :- Is the ratio of load to effort assuming no energy loss due to friction

$$\boxed{IMA = \frac{L}{E}}, \text{ No friction}$$

Velocity Ratio :- Is the ratio of distance moved by effort to the distance moved by the load.

$$\text{Velocity Ratio} = \frac{\text{Distance Moved by Effort}}{\text{Distance Moved by load}}$$

$$\boxed{V.R = \frac{S_E}{S_L}}$$

→ It is a unit less quantity.

Efficiency:- Is the ratio of work out put to work input

$$\text{Efficiency} = \frac{\text{Work out put}}{\text{Work in put}}$$

$$\boxed{\eta = \frac{W_{out}}{W_{in}} \times 100\%}$$

Since, Work out put = (load) (Distance of load) W_{out}
(L) (S_L)
Work input = (Effort (Distance of Effort)

$W_{in} = (E) (S_E)$ Then we have ;

$$\eta = \left(\frac{W_{out}}{W_{in}} \right) 100\%$$

$$\left[\eta = \frac{(L)(S_L)}{(E)(S_E)} \right] = 100\%$$

$$\boxed{\eta = \left(\frac{MA}{VR} \right) 100\%}$$

Conceptual Examples

1. Can a simple machine multiply Energy ? Explain

Explanation:- No. That will violate conservation of energy

2. Can a simple machine multiply force and speed at a time ? Explain

Explanation:- No. Energy can not be created or destroyed.

Illustrative examples

3. If a force of 100N is applied on a simple machine to lift a load of 50 kg to a height of 1m assuming the distance moved by the applied force to be 8m .calculate the;

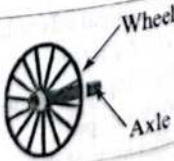
- A) Effort
- B) Load
- C) Mechanical advantage
- D) Velocity ratio
- E) Work input
- F) Work out put
- G) Efficiency of the machine

Solution:

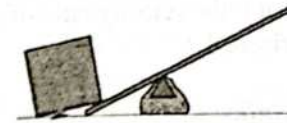
- A) Effort = Applied force = 100N
 B) Load = Weight = $Mg = (50)(10) = 500$
 C) $MA = \frac{L}{E} = \frac{500}{100} = 5$
 D) $VR = \frac{S_E}{S_L} = \frac{8}{1} = 8$
 E) $W_{in} = (E)(S_E) = (100)(8) = 800J$
 F) $W_{out} = (L)(S_L) = (500)(1) = 500J$
 G) $\eta = \left(\frac{W_{out}}{W_{in}} \right) 100\% = \left(\frac{500}{800} \right) 100\% = 62.5\%$

5.3 Types of Simple Machines

There are six simple machines. They are the lever, inclined plane, wedge, screw, wheel and axle, and pulley.

Simple Machine	Picture
Inclined plane	
Wedge	
Screw	
Wheel and Axle	

Lever



Pulley

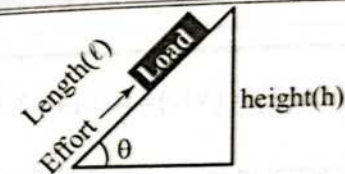


Now, let us study the Mechanical advantage, velocity ratio and efficiency of each Simple Machines.

Inclined plane:- Is a Sloping Surface that is used to lift a body to some height.

$$MA = \frac{\text{load}}{\text{effort}} = \frac{L}{E}$$

$$VR = \frac{\text{Length}}{\text{height}} = \frac{L}{h}$$



Inclined plane is also called a ramp and is a force multiplier machine.

Illustrative Example

4. If an effort of 80N is needed to push a 240N box up a ramp of 40m length and 8m height. Calculate ;

- A) MA
 B) VR
 C) η of the ramp

Solution:

$$A) MA = \frac{L}{E} = \frac{240}{80} = 3$$

$$B) VR = \frac{L}{h} = \frac{40}{8} = 5$$

$$C) \eta = \left(\frac{MA}{VR} \right) 100\% = \left(\frac{3}{5} \right) 100\% = 60\%$$

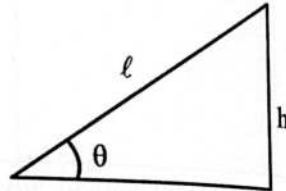
5. What is the velocity ratio of an inclined plane of 30° inclination from the horizontal?

Solution:

$$VR = \frac{L}{h}$$

$$\sin \theta = \frac{h}{L}$$

$$VR = \frac{1}{\sin \theta} = \frac{1}{0.5} = 2$$



6. If the efficiency of an inclined plane is obtained to be 0.8, then what is the mechanical advantage assuming the velocity ratio is 4?

Solution:

$$\eta = \frac{MA}{VR} \Rightarrow MA(\eta) = (VR) = (0.8)4 = 3.2$$

7. What is the input energy in to a ramp of 50% efficiency if the output energy is 450 J?

Solution:

$$\eta = \left(\frac{W_{out}}{W_{in}} \right) 100\%$$

$$50\% = \left(\frac{450}{W_{in}} \right) 100\%$$

$$0.5 = \frac{450}{W_{in}} \Rightarrow W_{in} = \frac{450}{0.5}$$

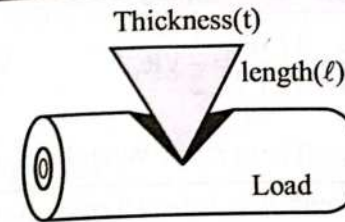
$$W_{in} = 900J$$

Wedge:- Is a piece of metal or wood thicker at one edge, thinner at the other used to split a body

$$MA = \frac{L}{E}$$

$$VR = \frac{\text{Length}}{\text{Thickness}} = \frac{L}{t}$$

$$\eta = \frac{MA}{VR} = \frac{Lt}{EL}$$



Illustrative Examples

8. An effort of 200N is applied on to a Wedge of 4cm thick and 12cm long to split a log of 500N into parts. calculate

- A) MA
B) VR
C) η of the wedge

Solution

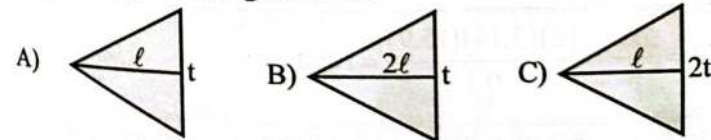
$$A) MA = \frac{L}{E} = \frac{500}{200} = 2.5$$

$$B) VR = \frac{L}{t} = \frac{12}{4} = 3$$

$$\eta = \frac{MA}{VR} = \frac{2.5}{3} = 0.83$$

$$C) \eta = 83\%$$

9. Which Wedge has the greater V.R.



Solution

$$A) VR_1 = \frac{L}{t}$$

$$B) VR_2 = \frac{2L}{t} = 2 \left(\frac{L}{t} \right) = 2VR_1$$

$$C) VR_3 = \frac{L}{2t} = \frac{1}{2} \left(\frac{L}{t} \right) = \frac{1}{2} VR_1$$

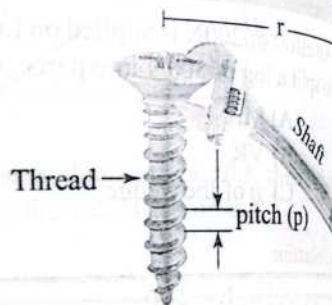
Therefore, Wedge B has greater Volatility Ratio

Screw :- Is a cylinder with helical threads around it and used to fix objects together.

$$VR = \frac{\text{circumference of shaft}}{\text{Pitch}}$$

$$VR = \frac{2\pi r}{P}$$

$$VR = \frac{\pi d}{P}$$



Where : r = radius of shaft

d = diameter of shaft

p = Pitch

Illustrative Example

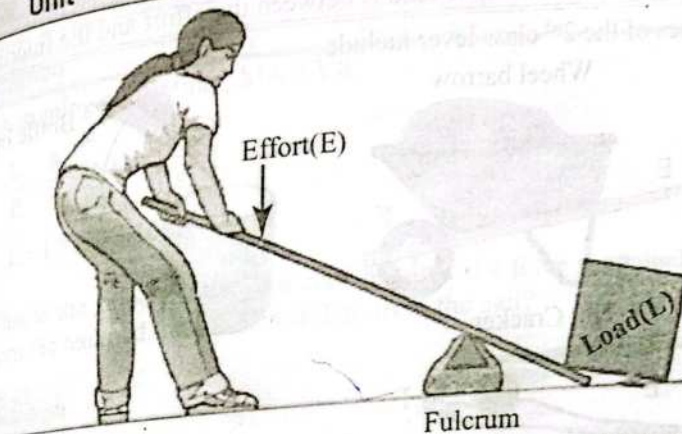
10. What is the velocity ratio of a Screw of Pitch 10mm if a shaft of 15.9cm radius makes one cycle.

Solution

$$VR = \frac{2\pi r}{p} = \frac{(2)(3.14)(15.9)}{0.1} = 1000$$

Lever:- Is a rigid bar of metal or wood free to turn about a pivot point called fulcrum and is used to raise an object.

A **lever** is a bar that rotates around a pivot - point called **fulcrum**. Lever can multiply an **effort** or multiply distance and speed.



Effort Arm:- Is the part of the lever that extends from the fulcrum to the effort. **load arm**, is then the part of the lever that extends from the fulcrum to the load.

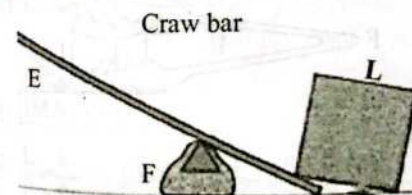
Classes of a Lever

Depending on the relative positions of a fulcrum, a load and an effort, there are three classes of a lever. Those are 1st class, 2nd class, and 3rd class lever.

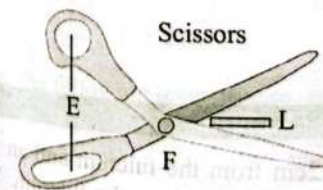
Now, let us investigate each class of lever one by one.

First - Class Lever:- The fulcrum is between the load and the effort.

Examples of the 1st class lever includes



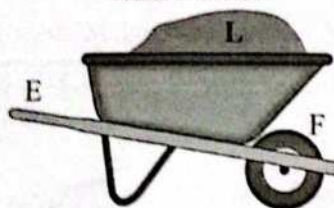
Claw hammer



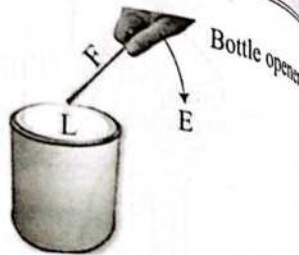
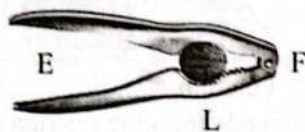
Second - class Lever:- The load is between the effort and the fulcrum

Examples of the 2nd class lever include

Wheel barrow



Nut Cracker

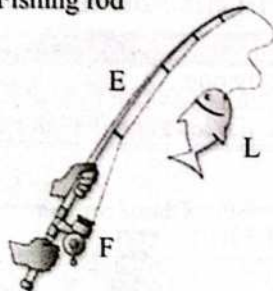


VR is always greater than one

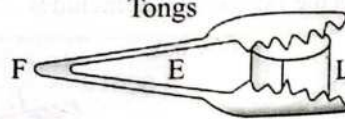
Third - class Lever:- The effort is between the load and fulcrum

Examples of the 3rd class lever include;

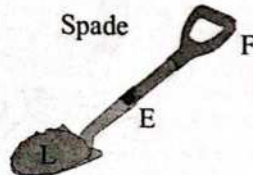
Fishing rod



Tongs



Spade



Illustrative Example

11. In a nut cracker, a nut is located 2cm from the fulcrum and an input force of 20N is applied at the handles 10cm from the fulcrum. What force is applied on the nut ?

Solution

Assuming no friction ; $MA = VR$

$$\frac{L}{E} = \frac{s_E}{s_L} \Rightarrow L = \left(\frac{s_E}{s_L} \right)$$

$$E = \left(\frac{10}{2} \right) 20 = 100N$$

12. What is the velocity ratio of a claw hammer if a force is applied 30cm from the nail and the fulcrum is 2cm from the nail?

Solution

$$VR = \frac{s_E}{s_L} = \frac{28}{2}$$

$$VR = 14$$

13. An iron bar 3m long is used to lift a 60kg block. If the fulcrum is 80cm from the block, find

- A) IMA
B) Effort, E

Solution

$$A) IMA = VR = \frac{s_E}{s_L} = \frac{2.2}{0.8}$$

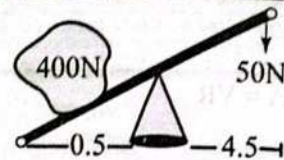
$$= 2.75$$

$$B) IMA = VR$$

$$\frac{L}{E} = \frac{s_E}{s_L} \Rightarrow E = L \left(\frac{s_L}{s_E} \right) = 600 \left(\frac{0.8}{2.2} \right)$$

$$E = 218N$$

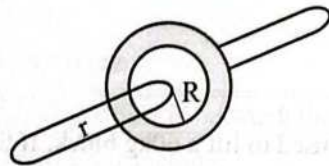
14. For the following lever system, find the VR



Solution

$$VR = \frac{S_E}{S_L} = \frac{4.5}{0.5} = 9$$

Wheel and Axle: Is a wheel secured to a rod called an axle and is used to multiply force or speed



$$VR = \frac{\text{Circumference of Wheel}}{\text{Circumference of Axle}} = \frac{2\pi R}{2\pi r}$$

$$VR = \frac{R}{r} \quad VR \text{ can } > 1, < 1 \text{ or } = 1$$

Illustrative Example

15. Using a wheel and axle, a 400N load is lifted by a 50N force applied at the rim of the wheel. of the radii of the wheel and axle are 85cm and 6cm respectively, determine

- A) MA
- B) VR
- C) η of the wheel and axle

Solution

$$A) MA = \frac{L}{E} = \frac{400}{50} = 8$$

$$B) VR = \frac{R}{r} = \frac{85}{6} = 14.2$$

$$C) \eta = \frac{MA}{VR} = \frac{8}{14.2} = 0.56 = 56\%$$

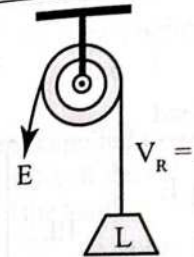
Pulley: Is a wheel with a grooved surface over which a rope or a chain passes

The VR value of a pulley is equal to the number of strings or ropes supporting the load.

VR of a pulley can be greater than one > 1 , less than one < 1 or equal to one $= 1$

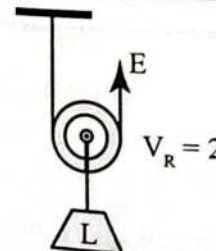
A pulley system is divided into three as fixed, movable and compound.

Fixed pulley: Is a pulley with a fixed axle and a rope wrapped over the top.



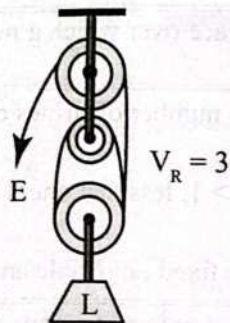
A Fixed pulley has a velocity ratio of one $VR = 1$ and is used to change direction of the applied force.

Movable Pulley :- Is a pulley with an axle that is free to move up and down with the load



A Movable Pulley has a velocity ratio of two $VR = 2$ and is used to multiply force.

Compound pulley:- Is a combination of fixed and movable pulley. It is also called a block and tackle.

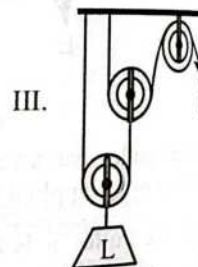
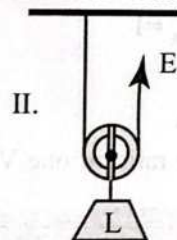
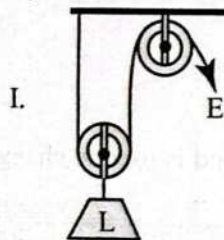


Illustrative Examples

16. For each of the pulley Systems, determine ;

A) VR

B) The effort needed to lift the 100N load



Solution

I. A) VR = 2

B) $2E = 100 \Rightarrow E = 50\text{N}$

II. A) VR = 2

B) $2E = 100 \Rightarrow E = 50\text{N}$

III. A) VR = 4

B) $4E = 100 \Rightarrow E = 25\text{N}$

17. Which kind of pulley makes your effort force larger?

A) Fixed pulley

- B) Movable pulley
C) Compound pulley
D) Fixed pulley and movable pulley

Answer: B

18. Which simple machine can Not be used to increase force?
A) Lever
B) Wheel and axle
C) Fixed pulley
D) Movable pulley

Answer: C

19. In a simple machine effort of 120N acts through 3m to raise a load of 480N to a height of 0.6m. The efficiency of the machine is:
A) 70%
B) 80%
C) 90%
D) 100%

Solution

$$\eta = \frac{MA}{VR} = \left(\frac{480/120}{3/0.6} \right) 100\% = \left(\frac{4}{5} \right) 100\% = 80\%$$

Answer: B

20. A 100N force is applied to a load to a height of 10m using a machine of efficiency 60%. If the effort moved distance of 50m what is the magnitude of the load?

- A) 100N
B) 200N
C) 300N
D) 400N

Solution

$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta (VR)$$

$$\frac{L}{E} = (0.6) \left(\frac{50}{100} \right)$$

$$L = (100) (0.6) (5)$$

$$L = 300\text{N}$$

Answer: C

21. A machine with a velocity ratio of 12 needed 1600J of work to raise a load of 1200N to a height of 1m. What is the efficiency of the machine?
A) 50%
B) 60%
C) 70%
D) 75%

Solution

$$\eta = \left(\frac{W_{\text{out Put}}}{W_{\text{in Put}}} \right) 100\%, W_{\text{output}} = LSL = (1200)(1) = 1200J$$

$$\eta = \left(\frac{1200}{1600} \right) 100\%$$

$$\eta = 75\%$$

22. A simple machine has an efficiency of 0.75 and velocity ratio of 12. What is the mechanical advantage of the machine?

A) 9 B) 12 C) 6 D) 3

Solution

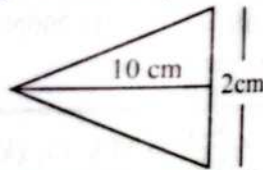
$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta(VR)$$

$$MA = (0.75)(12)$$

$$MA = 9$$

23. A 10cm long and 2cm wide metal wedge is used to split a wood. What is the velocity ratio of the wedge?

A) 3 C) 6
B) 5 D) 9

*Solution*

$$VR = \frac{\ell}{t} = \frac{10}{2}$$

$$VR = 5$$

24. A screw shaft has a diameter of 4 cm and its adjacent threads are 0.314cm apart. What is the velocity ration of the screw?

A) 10 B) 20 C) 30 D) 40

*Answer: B**Solution*

$$VR = \frac{2\pi r}{p} = \frac{2(3.14)(2)}{0.314}$$

$$VR = 40$$

Answer: D

25. Which one of the following is true about simple machines?

A) Velocity ratio is usually less than mechanical advantage
B) Mechanical advantage is always less than one
C) For speed multiplier machine, $VR < 1$
D) For a force multiplier machine, $MA < 1$

Hint: $VR < 1$ or $MA < 1$, speed multiplier machine

$VR > 1$ or $MA > 1$, force multiplier machine

$VR = 1$ or $MA = 1$, direction changer machine

Answer: C

26. A 50N force is needed to raise a 20 kg object a height of 3m. If the length of the plane is 15m, What is its efficiency?

A) 75% B) 80% C) 85% D) 90%

$$\text{Hint: } \eta = \frac{MA}{VR} = \frac{L/E}{SE/SL} = \frac{200/50}{15/3} = 0.8$$

$$\eta = 80\%$$

Answer: B

27. If an inclined plane of 4m length and 1m height has an efficiency of 50%, what is its mechanical advantage?

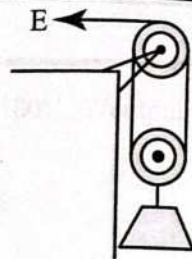
A) 3 B) 2 C) 5 D) 6

Solution

$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta(VR) = (0.5)(4) = 2$$

Answer: B

28. What is the purpose of the pulley system shown below



A) Speed multiplier

B) Force multiplier

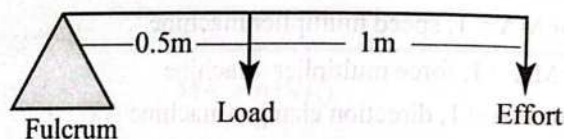
Hint: $VR = 2$

C) Direction change

D) Has no purpose

Answer: B

29. What is the velocity ratio of the lever shown below



A) 2

B) 0.5

C) 3

D) 5

$$\text{Hint: } VR = \frac{SE}{SL} = \frac{1.5}{0.5}$$

$$VR = 3$$

Answer: C

30. A 7 cm thick and 15 cm long wedge is used to pierce an object of 2m long and 20 cm diameter. What is the velocity ratio of the wedge?

A) 1

B) 10

C) 0.47

D) 2.14

$$\text{Hint: } VR = \frac{\ell}{t} = \frac{15}{7}$$

$$VR = 2.14$$

Answer: D

31. What is the velocity ratio of the pulley system shown



A) 4

B) 3

C) 5

D) 6

Hint: Velocity ratio = number of ropes supporting the block

Answer: B

End of unit Questions and problems

i. Give short Answers for the Following Questions

1. What is a Simple Machine?
2. What are the purposes of Simple Machines
3. List the Six types of Simple Machines
4. Define the following terms
 - a) Effort
 - b) Load
 - c) Mechanical advantage
 - d) Velocity Ratio
 - e) Work input
 - f) Work output
 - g) Efficiency of simple machines
5. What is the difference between Ideal Mechanical Advantage and Actual Mechanical Advantage
6. Describe the three classes of a lever
7. Explain the three types of pulley
8. How can we determine velocity ratio of a pulley system
9. Give examples for the force multiplier ; speed . multiplier and direction changer simple machine.
10. How can we determine the purpose of a simple machine based on its mechanical advantage or velocity ratio value ? Explain

ii. Solve the Following Problems

11. A 6000N block is pushed up a ramp by a force of 300N - Assuming no emerge lose ; calculate
 - A) MA
 - B) VR
 - C) Length of the ramp if its height is 10m
12. A 12cm long and a 3cm wide metal wedge is pushed into a wood . If there is no friction , calculate
 - A) VR
 - B) The load if the effort is 20N
13. If a lever raised a block 4m when the effort is moved 2m , what is the purpose of the lever ?
14. An effort of 30N moved a load of 150N , using a pulley . by how much does the machine multiply the effort ?
15. A Simple machine used an effort of 50N , through a distance of 8m to lift a load of 100N through a distance of 4m. What is the efficiency of the machine ?
16. A wheel and axle of radii 30cm and 5cm respectively is used to lift a bracket of water of 40 N out of a well . What is the
 - A) VR
 - B) Effort needed
 - C) Efficiency of the machine
17. A movable pulley is used to move a 140N load . If there is a 5N friction force,
 - A) Can this load be lifted with a 75N applied force
 - B) Would a fixed pulley does the hop instead?
18. The efficiency of an inclined plane is 50% .If the plane has a length of 4m and a height of 1m, What is its Mechanical Advantage?
19. On a 1.5m lever, a load is placed 0.5m away from the fulcrum, How large is the VR , if the lever is
 - A) 1st Class

- B) 2nd class
20. A Simple machine has an efficiency of 0.75 and a VR of 12. Determine the MA and the load that can be moved by an effort of 100N
21. A 40 percent efficient machine performs 200J of useful work . What input work was introduced ?
22. A 60 % efficient machine lifts a 10kg mass at a speed of 3m/s . What is the required input power ?
23. What must be the thickness of a wedge of 20cm long if it is desired that the input force be one - tenth of the out put force ?
24. The handle of a Screw jack is 50cm long . If the screw has five threads per centimeter, What is the ideal mechanical advantage of the Screw.

I. Short answers and explanations

1. It is a machine that helps us to do work easier
2. They help us to multiply force or to multiply Speed or to change direction
3. Inclined plane, wedge, screw, lever, wheel and axle and pulley
4. a) Is the force applied on the machine
b) Is the force the machine exerted on the object .
c) MA is the ratio of load to effort
d) VR is the ratio of distance moved by the effort to the distance moved by the load
- e) Is the work done by the effort $W_{in} = (E) (SE)$
- f) Is the work done by the machine . $W_{out} = (L) (SL)$
- g) Is the ratio of work output to work input

$$\eta = \frac{W_{out}}{W_{in}} = \frac{MA}{VR}$$

5. AMA is the ratio of load to effort in the presence of friction but IMA is the ratio of load to effort in the absence of friction
6. 1st class, fulcrum is between load and effort

2nd class, load is between effort and load

3rd class, effort is between load and fulcrum

7. Fixed, movable and compound pulley
8. VR of, a pulley is equal to the number of strings supporting the load
9. Force multiplier :- Inclined plane, lever, compound pulley

Speed multiplier :- lever, wheel, and axle

Direction changer:- pulley, wheel and axle

10. If MA or VR > 1, force multiplier

MA or VR < 1, speed multiplier

MA or VR = 1, direction changer

II. Solution to the End of Unit Problems

11.

$$A) MA = \frac{6000}{300} = 20$$

$$B) VR = MA = 20$$

$$C) VR = MA \Rightarrow \frac{L}{h} = \frac{L}{E} \Rightarrow L = \left(\frac{L}{E}\right)h = \left(\frac{6000}{300}\right)(10) = 200m$$

$$12. A) VR = \frac{L}{t} = \frac{12}{3} = 4$$

$$B) MA = VR \Rightarrow \frac{L}{E} 4L = E(4) = (20)(4)80N$$

$$13. MA = \frac{S_E}{S_L} = \frac{2}{4} = 0.5, \text{ speed multiplier}$$

$$14. MA = \frac{L}{E} = \frac{150}{30} = 5, \text{ it multiplied the effort five times.}$$

$$15. \eta = \frac{MA}{VR} = \frac{(L)(S_L)}{(E)(S_E)} = \frac{(100)(4)}{(50)(8)} = 1 = 100\%$$

$$16. A) VR = \frac{R}{r} = \frac{30}{5} = 6$$

$$B) MA = VR \Rightarrow \frac{L}{E} = \frac{R}{r} \Rightarrow E = L \left(\frac{r}{R}\right) = 40 \left(\frac{5}{30}\right) = 6.7N$$

$$C) \eta = \frac{MA}{VR} = 1 = 100\%$$

$$17. A) MA = \frac{L}{E} = \frac{145}{75} = 2, 150 > 145 \text{ yes!}$$

$$B) MA = \frac{L}{E} = \frac{145}{75} = 1, 75 < 145 \text{ No!}$$

$$18. \eta = \frac{MA}{VR} \Rightarrow 0.5 = \frac{MA}{4}, \text{ Hence, } MA = 2.$$

$$19. A) VR = \frac{S_E}{S_L} = \frac{1}{0.5} = 2.$$

$$B) VR = \frac{S_E}{S_L} = \frac{1.5}{0.5} = 3$$

$$\eta = \frac{MA}{VR} \Rightarrow MA = \eta(VR) = 0.75(12) = 8.5$$

$$20. \text{ Since } MA = \frac{L}{E} \Rightarrow L = MA(E) = 8.5(100) = 850N$$

$$21. \eta = \frac{W_{Out}}{W_{In}} \Rightarrow 0.4 = \frac{200}{W_{In}}, W_{In} = 500J$$

$$22. \eta = \frac{W_{Out}}{W_{In}} = \frac{P_{Out}}{P_{In}}, P_{Out} = mgv = (10)(3)(10) = 300w$$

$$\Rightarrow P_{In} = \frac{P_{Out}}{\eta} = \frac{300}{0.6} = 500 \text{ Watt}$$

$$23. IMA = VR \Rightarrow \frac{L}{t} = \frac{L}{E} \Rightarrow t = L \left(\frac{E}{L}\right) = 20 \left(\frac{1}{10}\right) = 2cm$$

$$24. IMA = VR = \frac{2\pi R}{P} = \frac{2(3.14)(50)}{0.2} = 1570$$

UNIT 6

6. Mechanical Oscillation and Sound Wave

- 6.1 Oscillations and waves
- 6.2 Simple pendulum and spring - mass system
- 6.3 What are the Types of waves
- 6.4 What are the Properties of Waves
- 6.5 What is Sound Wave

6. Mechanical Oscillation and Sound Wave

Hello reader, we are very excited to meet you in this interesting unit where you will get to know term such as oscillation, wave and disturbance, be familiar with terms such as frequency, period and wavelength, explain types of waves, describe common properties of waves, find out period and frequency of oscillation of simple pendulum and spring-mass system, define sound waves, and understand the production and application of echo. For sure, you will love it. Enjoy!

6.1 Oscillations and Waves

Waves and oscillations are phenomena's generated by natural or artificial processes.

Now, let us define them one by one.

Wave: Is a continues disturbance that moves from place to place carrying energy.

A wave may be mechanical or electromagnetic, and a transverse or a longitudinal, all of which we will discuss in the coming session.

Oscillation: Is a periodic or repeated here and there, up and down or to and fro motion of a body.

Motion of simple pendulum and the motion of spring-mass system are best examples of oscillatory motion.

The terms that are used to describe wave motion and oscillation are the following;

- ↪ **Equilibrium position:** Is the rest or undisturbed position of a particle or a field.
- ↪ **Amplitude, A:** Is the maximum displacement of a particle from the equilibrium position.
- ↪ Its unit is meter(m)

→ Period, T: Is the time taken to cover one cycle.

$$\text{Period} = \frac{\text{Time taken}}{\text{Number of cycles}}$$

Its unit is second(s)

→ Frequency, F: is the number of cycles made per second

$$\text{Frequency} = \frac{\text{Number of cycles}}{\text{Time taken}}$$

Its unit is hertz (Hz)

Frequency is the reciprocal of period,

$$f = \frac{1}{T}$$

⇒ 1Hz = S⁻¹ read as per second

→ Wavelength, λ (lambda): Is the distance between identical points or complete cycles.

Its unit is meter (m)

→ Wave speed, V: Is the distance moved by a particle per second.

$$\text{Wave speed} = \frac{\text{Wave length}}{\text{Time taken}}$$

$$V = \frac{\pi}{T}; f = \frac{1}{T}$$

$$\boxed{V = \lambda f}$$

Its unit is meter per second, (m/s)

Illustrative Examples

1. A body 40 oscillations in 20 seconds. What is its

A) Period of oscillation

B) Frequency of oscillation

Solution:

$$\text{A) period} = \frac{\text{Time taken}}{\text{Oscillation made}}$$

$$T = \frac{20}{40} = 0.5 \text{ sec}$$

$$\text{B) Frequency} = \frac{\text{Oscillation made}}{\text{Time taken}} = \frac{40}{20} = 2 \text{ Hz}$$

2. If the frequency of oscillation of a body is found to be 5Hz.

A) What does it mean when we say 5Hz

B) What is the period of oscillation of the body

Solution:

A) 5Hz means, the body moved 5 complete cycle in just one second.

$$\text{B) } T = \frac{1}{f} = \frac{1}{5} = 0.2 \text{ sec}$$

3. An oscillating body takes 10 seconds to move a 50cm complete cycle. What is the speed of the oscillating body?

Solution:

$$V = \lambda f = \frac{\lambda}{T}$$

$$V = \frac{0.5}{10} = 0.05 \text{ m/s}$$

Match the items in "A" Column with those in column "B"

A

4. frequency

5. period

6. amplitude

7. equilibrium

B

A. distance moved in one cycle

B. cycles moved in one second

C. time taken to move one cycle

D. maximum displacement

8. wave speed

9. wavelength

E. zero displacement
 F. distance per unit time
 G. speed per unit time

Answers

4. B

6. D

8. F

5. C

7. E

9. A

6.2 Simple Pendulum and Spring-Mass System

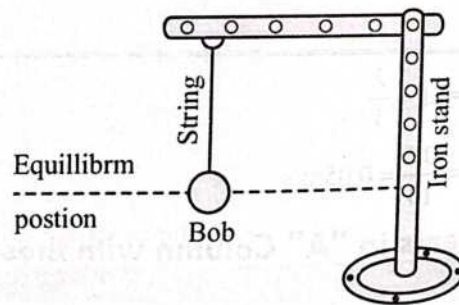
The most common examples of periodic motion are simple pendulum and spring-mass system.

Periodic motion: Is a motion that repeats itself over and over again.

Now, let us make use of simple relations to find the period and frequency of this oscillators.

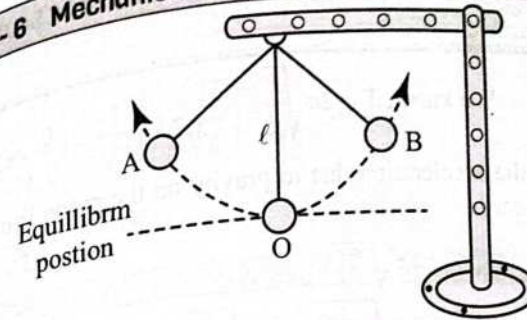
Simple Pendulum

It consists of a point mass called **bob** suspended by a massless string fixed at a frictionless stand as shown below:



A typical simple pendulum

If the bob is displaced and then released, from some height, it oscillate here and there as shown below:



When the bob is taken from point O to point A and then released, it moves from A to O then to point B, and from the transformation of energy the bob will move back to O and A and the cycle repeats.

And, the time it takes the bob to come back to point A that is to cover one cycle is obtained by:

$$T = 2\pi \sqrt{\frac{\ell}{g}}$$

Where : T = period of simple - pendulum

ℓ = length of the string

g = acceleration due to gravity

And, frequency of oscillation of the simple-pendulum is obtained by:

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{\ell}}$$

This relation is derived from the fact that , frequency and period of oscillation are reciprocal to each other.

$$\text{That is, } f = \frac{1}{T}$$

Conceptual Example

10. Will there be any difference in the period of oscillation of a simple pendulum on the moon and on the earth?

Explanation:

$$\text{We know, } T = 2\pi \sqrt{\frac{l}{g}}$$

And, the acceleration due to gravity on the moon is one-sixth that on the earth.

$$T_{\text{earth}} = 2\pi \sqrt{\frac{l}{g}}$$

$$T_{\text{moon}} = 2\pi \sqrt{\frac{l}{g_{\text{moon}}}} = 2\pi \sqrt{\frac{l}{\frac{1}{6}g}}$$

$$T_{\text{moon}} = 2\pi \sqrt{\frac{6l}{g}} = \sqrt{6} \left(2\pi \sqrt{\frac{l}{g}} \right)$$

$$T_{\text{moon}} = \sqrt{6} T_{\text{earth}}$$

On the moon, the period of oscillation of the pendulum increases

11. What will happen to the period of oscillation of a simple pendulum, if the bob mass is doubled?

Explanation:

$$\text{Since, } T = 2\pi \sqrt{\frac{l}{g}}$$

Period of oscillation of a simple pendulum does not depend on the mass of the bob. It will remain the same.

12. What will happen to the frequency of a simple pendulum if the string length is..

A) doubled

B) halved

Explanation:

$$\text{A) } T' = 2\pi \sqrt{\frac{2l}{g}} = \sqrt{2} \left(2\pi \sqrt{\frac{l}{g}} \right)$$

$$T' = \sqrt{2} T, \text{ increases}$$

$$\text{B) } T' = 2\pi \sqrt{\frac{\frac{l}{2}}{g}} = \frac{1}{\sqrt{2}} \left(2\pi \sqrt{\frac{l}{g}} \right) = \frac{1}{\sqrt{2}} T, \text{ decrease}$$

$$T' = \frac{1}{\sqrt{2}} T, \text{ decreases}$$

Illustrative Examples

13. What is the period of oscillation of a simple pendulum of length 90cm on the surface of the earth?

Solution:

$$T = 2\pi \sqrt{\frac{l}{g}} = 2\pi \sqrt{\frac{0.9}{10}}$$

$$T = \frac{6\pi}{10} = 1.9 \text{ second}$$

14. If the period of oscillation of a simple pendulum is $\sqrt{\frac{2}{3}}$ second on the earth surface, what will be the period of oscillation of this pendulum on the moon where $g_{\text{moon}} = \frac{1}{6} g$

Solution

$$T = 2\pi \sqrt{\frac{l}{g}} = \sqrt{\frac{2}{3}}$$

$$T_{\text{moon}} = 2\pi \sqrt{\frac{l}{g_{\text{moon}}}} = 2\pi \sqrt{\frac{l}{\frac{1}{6}g}}$$

$$T_{\text{moon}} = 2\pi \sqrt{\frac{6l}{g}} = \sqrt{6} \left(2\pi \sqrt{\frac{l}{g}} \right)$$

$$T_{\text{moon}} = (\sqrt{6}) \left(\sqrt{\frac{2}{3}} \right) = \sqrt{\frac{12}{3}} = \sqrt{4}$$

$$T_{\text{moon}} = 2 \text{ sec}$$

15. A simple pendulum of length 900cm is found to have a period of 2 second. What is the acceleration due to gravity of the place where oscillation is made?

Solution:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

$$\frac{T}{2\pi} = \sqrt{\frac{l}{g}}$$

$$\frac{T^2}{4\pi^2} = \frac{l}{g}$$

$$g = \frac{4\pi^2 l}{T^2} = \frac{(4\pi^2)(9)}{\pi^2}$$

$$g = 36 \text{ m/s}^2$$

16. What is the frequency of a simple pendulum of length 40cm on the earth surface?

Solution:

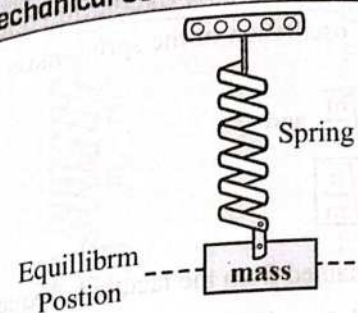
$$f = \frac{1}{2\pi} \sqrt{\frac{g}{l}}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{10}{0.4}} = \frac{1}{2\pi} \sqrt{\frac{100}{4}}$$

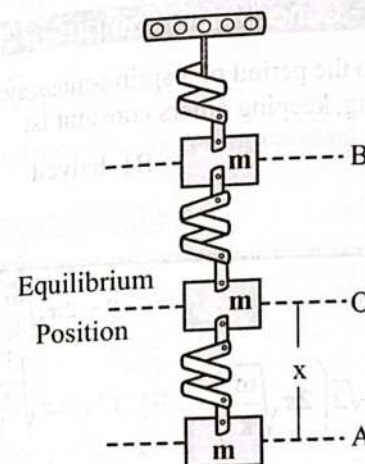
$$f = \frac{5}{2\pi} \text{ Hz}$$

Spring - mass System

It consists of a mass attached to one of the free end of a spring as shown below:



If we stretch or compress the system and then release, it will oscillate up and down.



For example, if we stretch the system down to point A and then release, it will move from A to O then to B and back to point A. And, the cycle repeats.

The time taken by the system to complete, one cycle that is to come back to point A is obtained by:

$$T = 2\pi \sqrt{\frac{m}{k}}$$

Where: T = period of oscillation of the spring-mass system

m = mass of the block

k = spring constant or force constant of the spring

Moreover, frequency of oscillation of the spring-mass system is obtained by:

$$T = 2\pi \sqrt{\frac{m}{k}}, \text{ and}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

The above relation is obtained from the fact, that, frequency and period of oscillation are reciprocal to each other. That is, $f = \frac{1}{T}$

Conceptual Example

17. What will happen to the period of a spring-mass system if the mass attached to the spring, keeping others constant is:

A) double

B) halved

Explanation:

$$T = 2\pi \sqrt{\frac{m}{k}}$$

$$T = 2\pi \sqrt{\frac{m}{k}}$$

$$\text{A) } T' = 2\pi \sqrt{\frac{2m}{k}} = \sqrt{2} \left(2\pi \sqrt{\frac{m}{k}} \right) \quad \text{B) } T' = 2\pi \sqrt{\frac{\frac{1}{2}m}{k}} = \frac{1}{\sqrt{2}} \left(2\pi \sqrt{\frac{m}{k}} \right)$$

$$T' = \sqrt{2}T, \text{ increases}$$

$$T' = \frac{1}{\sqrt{2}} T$$

18. What will happen to the period of a spring-mass system if the spring length, keeping others constant is:

A) doubled, connected in series

B) halved, connected in parallel

Explanation:

$$\text{A) } T = 2\pi \sqrt{\frac{m}{k'}}$$

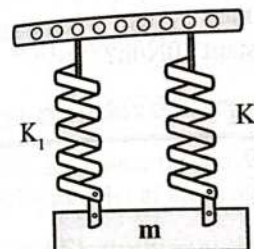
When spring length increases, its spring constant decreases by the same amount.



$$T' = 2\pi \sqrt{\frac{m}{k_1}} = 2\pi \sqrt{\frac{m}{k/2}}$$

$$T' = \sqrt{2}T, \text{ increases}$$

When spring length decreases, its spring constant increases by the same amount.



$$F = F_1 + F_2$$

$$k'x = k_1 \times k_2 x, k_1 = k_2$$

$$k' = 2k$$

$$T' = 2\pi \sqrt{\frac{m}{k'}} = 2\pi \sqrt{\frac{m}{2k}}$$

$$T' = \frac{1}{\sqrt{2}} \left(2\pi \sqrt{\frac{m}{k}} \right)$$

$$T' = \frac{1}{\sqrt{2}} T, \text{ decrease}$$

$$x = x_1 + x_2$$

$$\frac{F}{K} = \frac{F}{k_1} + \frac{F}{k_2}, k_1 = k_2$$

$$\frac{1}{k'} = \frac{1}{k_1} + \frac{1}{k_2} = \frac{2}{k}$$

$$k' = \frac{k}{2}$$

Illustrative Example

19. What is the force constant of a spring with a period of oscillation of 2 second when 4kg mass is suspended on it?

Solution:

$$T = 2\pi \sqrt{\frac{m}{k'}}$$

$$\frac{T^2}{4\pi^2} = \frac{m}{k}$$

$$k = \frac{4\pi^2 m}{T^2} = \frac{4\pi^2 (4)}{\frac{\pi^2}{100}} = 1600 \text{ N/m}$$

20. What is the period of a spring-mass system when a mass of 0.9kg is attached to a spring of force constant 10N/m?

Solution:

$$T = 2\pi \sqrt{\frac{m}{k}} = 2\pi \sqrt{\frac{0.9}{10}}$$

$$T = 0.6\pi \text{ second}$$

21. What will happen to the frequency of a spring-mass system of initial frequency π Hz, if the force constant is doubled and the mass is halved?

Solution:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

$$f' = \frac{1}{2\pi} \sqrt{\frac{k'}{m'}}, k' = 2k \text{ and } m' = \frac{1}{2}m$$

$$f' = \frac{1}{2\pi} \sqrt{\frac{2k}{\frac{1}{2}m}} = \frac{1}{2\pi} \sqrt{\frac{4k}{m}}$$

$$f' = 2f = 2(\pi)$$

$$f' = 2\pi \text{ Hz}$$

22. What will happen to the period of oscillation of a spring-mass system if the mass is double and the force constant is halved?

Solution:

$$T_1 = 2\pi \sqrt{\frac{m_1}{k_1}}$$

$$T_2 = 2\pi \sqrt{\frac{m_2}{k_2}}, m_2 = 2m_1 \text{ and } k_2 = \frac{1}{2}k_1$$

$$T_2 = 2\pi \sqrt{\frac{2m_1}{\frac{1}{2}k_1}} = 2\pi \sqrt{\frac{4m_1}{k_1}} = 2 \left(2\pi \sqrt{\frac{m_1}{k_1}} \right) = 2T_1, \text{ doubled}$$

6.3 What are the Types of Waves?

Wave is a continues disturbance that travels from place to place carrying energy, with out transporting particles of the medium

I. Mechanical and Electromagnetic Waves

Depending on whether the wave requires material medium for its production and propagation, or not, we classify waves as mechanical and electromagnetic.

Mechanical Wave: Is a wave that requires material medium for its production and propagation.

For example, sound wave, string wave, water wave . . . etc. are mechanical waves.

Electromagnetic Wave: Is a wave produced by the interaction of electric and magnetic fields and can propagate in vacuum.

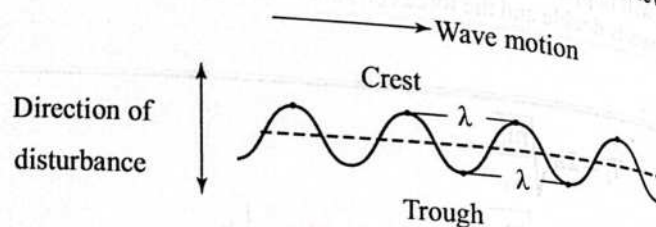
For example, x-ray, light ray, gamma ray....etc. are electromagnetic waves.

II. Transverse and Longitudinal Waves

And depending on the direction of wave motion and the direction of disturbance, we classify waves as transverse and longitudinal.

Transverse Wave: Is a wave for which the direction of the wave motion is perpendicular to the direction of disturbance made on the medium.

In such a wave, the direction of wave motion is at right angle to the direction of particles vibration



String wave and all the electromagnetic wave are transverse waves.

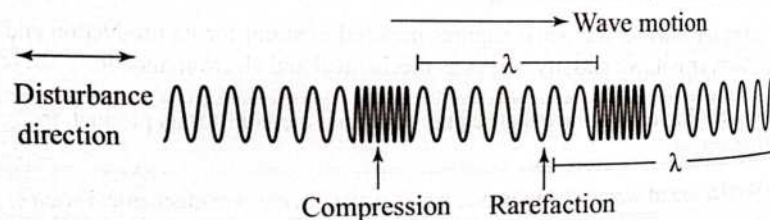
→ **Crest:** Is the highest point above the equilibrium position.

→ **Trough:** Is the lowest point below the equilibrium position.

And, the distance between two adjacent crests or adjacent troughs is equal to one wavelength.

Longitudinal Wave: Is a wave for which the direction of wave motion is parallel to the direction of disturbance.

For such a wave, the direction of the wave motion is the same to direction of particle vibration in the medium.



Sound wave and waves on a silky spring are examples of longitudinal wave.

→ **Compression:** Is region of high pressure where particles of the medium come closer together.

→ **Rarefaction:** Is region of low pressure where particles of the medium become far apart.

And, the distance between two adjacent compressions or adjacent rarefactions is equal to one wavelength.

Match the Item in Column 'A' with those in Column 'B'

- A**
23. Mechanical wave
 24. Electromagnetic wave
 25. Transverse wave
 26. Longitudinal wave
 27. Crest
 28. Trough
 29. Compression
 30. Rarefaction

- B**
- A) High pressure region
 - B) Low pressure region
 - C) Need medium
 - D) Can travel in vacuum
 - E) Highest point
 - F) Lowest point
 - G) Disturbance and propagation at 90°
 - H) Disturbance and propagation at 0° or 180°
 - I) Wave equation

Answers

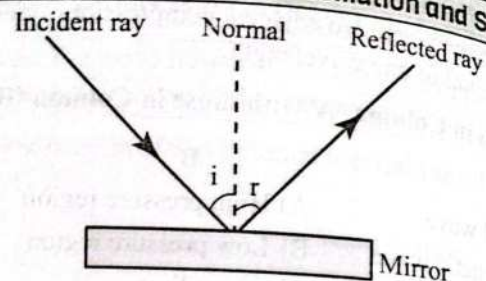
23.C	25.G	27.E	29.A
24.D	26.H	28.F	30.B

6.4 What are the Properties of Waves?

All waves exhibit common characteristic. These characteristics are reflection, refraction, diffraction and interference.

Reflection: Is bouncing back of a wave from a hard and smooth surface.

For example, if a light ray encounters a mirror, it will reflect back as shown below in to its initial medium.



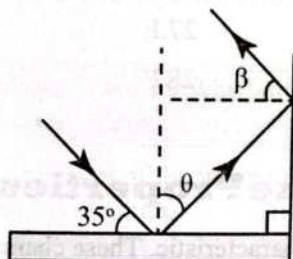
According to the law of reflection, the angle of incidence is equal to the angle of reflection.

$$\text{That is, } i = r$$

Illustrative Example

31. For the following case, where a light ray performed reflections on two perpendicular mirrors.

Find the value of θ and β



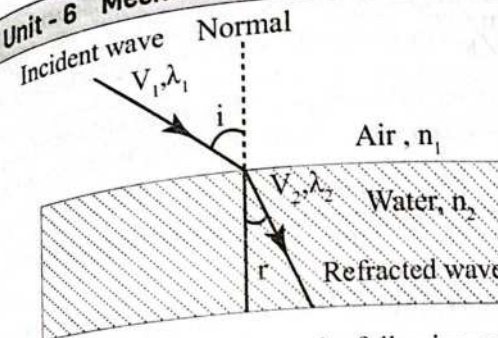
Solution:

Using the fact that complimentary angles add up to 90° , interior angles sum of a triangle is 180° and angle of incidence is equal to the angle of reflection we have,

$$\theta = 55^\circ \text{ and } \beta = 35^\circ$$

Refraction: Is the bending of a wave due to a change in its speed as it moves from one medium to the other.

For example, if light ray moves from air into water, its speed decreases and it bend towards the normal



According to Snell's law, we have the following relation.

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Where: n = refractive index

v = speed of the wave

λ = wavelength of wave

1 = medium one

2 = medium two

Illustrative Examples

32. If a light wave of wavelength 600nm entered from air into glass of refractive index 1.5 at an incidence angle of 53° , find the

- speed of light in glass
- angle of refraction
- wavelength of light in glass

Solution:

$$\text{A) } \frac{n_2}{n_1} = \frac{v_1}{v_2}$$

$$\frac{1.5}{1} = \frac{3 \times 10^8}{v_2}$$

$$v_2 = 2 \times 10^8 \text{ m/s}$$

$$B) \frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

$$\frac{\sin(53^\circ)}{\sin r} = \frac{1.5}{1} \Rightarrow \frac{0.8}{\sin r} = 1.5$$

$$\sin r = \frac{0.8}{1.5} \Rightarrow r = \sin^{-1}(0.53)$$

$$r = 32.20$$

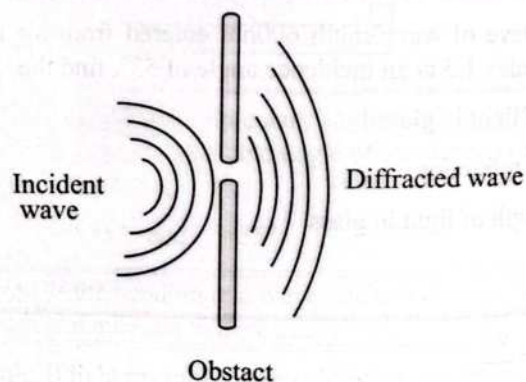
$$C) \frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2}$$

$$\frac{1.5}{1} = \frac{600}{\lambda_2}$$

$$\lambda_2 = 400 \text{ nm}$$

Diffraction: Is the spreading out of a wave through narrow opening or around sharp corners.

For example, if a wave faced an obstacle on its way as shown below, it will diffract.



Interference: Is the mixing up of two waves of the same kind

The magnitude of the resultant wave obtained after the mixing of the

waves is obtained by the super-position principle.

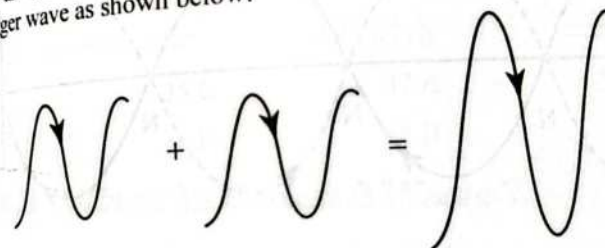
Superposition: States that, the magnitude of the resultant amplitude of the mixing waves at a point is equal to the vector sum of the amplitude of the mixing waves.

Superposition or interference of waves is of two types; constructive or destructive

Constructive Interference: Occurs when two waves that are in phase moving in the same direction with the same frequency and wavelength mix-up

Two waves are said to be in phase if their corresponding points reach maximum or minimum value at the same time.

As an example, when two waves interfere constructively, they form a bigger wave as shown below:

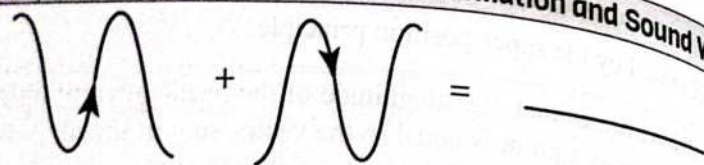


• The amplitude of the resultant wave is larger than the amplitude of the individual mixing waves.

Destructive Interference: Occurs when two waves that are out of phase moving in the same direction with the same frequency and wavelength mix-up.

Two waves are said to be out of phase if their corresponding points reach opposite displacements at the same time.

As an example, when two waves interfere destructively, they form a smaller wave as shown below

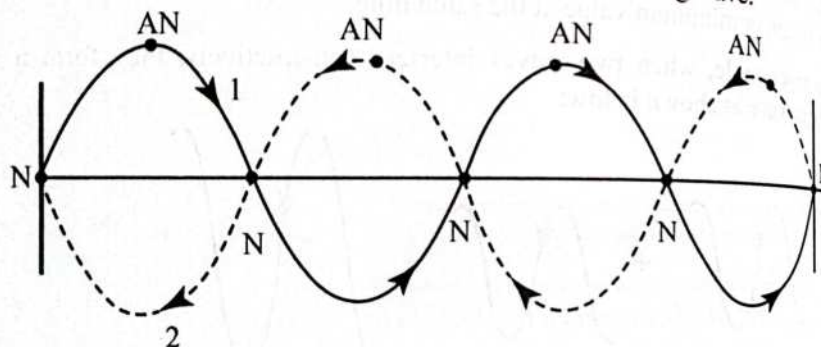


The amplitude of the resultant wave is smaller than the amplitude of the individual mixing waves.

Standing Wave

Is also called *stationary* wave and is created when two waves of the same type travelling in opposite directions mix up.

For example, plucking a guitar string produces standing wave.



This standing wave is formed when wave -1, travelling to the right mix up with wave -2, moving to the left.

Node, N: Is a point of zero displacement, and occurs due to destructive interference.

Anti-node, AN: Is a point of maximum displacement and occurs due to constructive interference.

What is more, the distance between successive nodes or adjacent anti-nodes is equal to half a wavelength, $\lambda/2$. And, that between a node and an anti-node is quarter of a wavelength, $\lambda/4$ okay.

Illustrative Example

Match the items in column 'A' with those in column 'B'

A

33. Reflection
34. Refraction
35. Diffraction
36. Interference
37. Constructive
38. Destructive
39. Node
40. Anti-Node

B

- A) In phase mixing
- B) Out of phase mixing
- C) Point of maximum displacement
- D) Point of zero displacement
- E) Bouncing back
- F) Mixing-up
- G) Spreading out
- H) Bending through medium
- I) Travelling Wave

Answers

33.E

35.G

37.A

39.C

34.H

36.F

38.B

40.D

6.5 What is Sound Wave?

Sound is a mechanical as well as a longitudinal wave produced by a body that is in a state of vibration.

- Sound to be produced and detected, there must be source, and medium for transmission

Speed of Sound

The speed sound depends on the state of mater of the substance through which it is moving. Therefore; the speed of sound in gases is different from its value through liquids and solids.

Speed of Sound in Air

The speed of sound in air increases as temperature, increases and it is obtained by;

$$v = 331 + 0.6T$$

$$v = 331 \sqrt{1 + \frac{T}{273}}$$

Where: 331m/s is the speed of sound in air at 0°C, and T is temperature in °C.

Speed of Sound in Liquid

The speed of sound in liquid has no significant variation as temperature changes.

$$v = \sqrt{\frac{B}{\rho}}$$

Where: B, is bulk modulus and is a measure of compressibility of the liquid.

ρ , is density of the liquid.

Speed of Sound in Solid

The speed of sound in solids does not significantly vary with a change in temperature.

$$v = \sqrt{\frac{Y}{\rho}}$$

Where: Y, is Young's modulus and is a measure of stiffness of the solid, ρ is density of the solid

Remember: The speed of sound is greatest in solids than it is in liquids and gases. And, it is greater in liquids than it is in gases. OK!

Illustrative Example

41. What is the speed of sound in air at 14°C ?

Solution

$$v = 331 + 0.6T$$

$$v = 331 + 0.6(14)$$

$$v = 340 \text{ m/s}$$

or

$$v = 331 \sqrt{1 + \frac{T}{273}}$$

$$v = 331 \sqrt{1 + \frac{14}{273}}$$

$$v = 340 \text{ m/s, Same}$$

42. What is the speed of sound in water of bulk modulus $2 \times 10^9 \text{ pa}$ and density 1000 kg/m^3 ?

Solution:

$$v = \sqrt{\frac{B}{\rho}}$$

$$v = \sqrt{\frac{2 \times 10^9}{1000}}$$

$$= 1400 \text{ m/s}$$

43. What is the speed of sound in steel of young's modulus $2 \times 10^9 \text{ pa}$ and density 7900 kg/m^3 ?

Solution

$$v = \sqrt{\frac{Y}{\rho}}$$

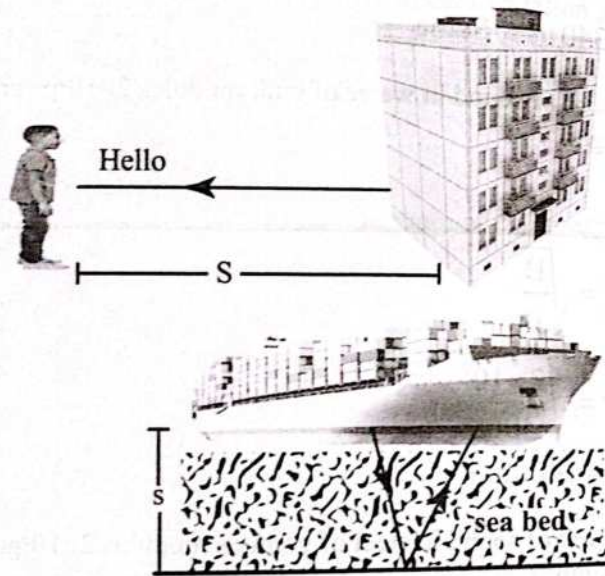
$$v = \sqrt{\frac{196 \times 10^9}{7900}}$$

$$= 4980 \text{ m/s}$$

Production of Echo

The reflection of sound from hard surface such as a rock, a cliff, a building, etc., is called an *echo*.

If you shout in front of a tall building or a mountain, you will hear the original sound and the reflected sound, that is the echo as two separate sounds. Echo, is used to determine the depth of an ocean and the distance of a building or a cliff from a sound source merely by talking the time taken by the sound wave to come back to the sound source after reflection.



In both cases, $2s = vt$

$$s = \frac{vt}{2}$$

Where: v = speed of sound in the given medium

t = total time taken of by sound to move from obstacle back to the source

s = distance between the sound source and the obstacle

Illustrative Example

44. At a moment when the speed of sound in air is 340m/s , a boy shouts "Hello" in front of a cliff and hears the echo after 5 seconds. How far is the cliff from the boy?

Solution:

$$s = \frac{vt}{2} = \frac{(340)(5)}{2}$$

$$s = 850\text{m}$$

45. What is the speed of sound in sea water if a ship 1500m above the sea bed detected an echo after 2 seconds?

Solution:

$$s = \frac{vt}{2} \Rightarrow v = \frac{2s}{t} = \frac{2(1500)}{2} = 1500\text{m/s}$$

Characteristics of Sound Wave

Some of the characteristics of sound wave are pitch, loudness and timber

Pitch: Is the lowness or highness of sound and it depends on the frequency of the sound wave.

In higher pitch sound, the particles of the medium vibrate more often past their rest position each second.

Example; girls have high pitch than boys.

Loudness: Is the magnitude or intensity of sound and it depends on the amplitude of the sound wave.

In louder sound, the particles of the medium move further away from their rest position.

Example, roar of lion is louder than mew of a cat.

Remember; sound level, that is loudness is measured in decibel (dB) and

sound is said to be polluted or painful when above 120dB.

Timber: Is the quality of sound and it depends on the tone produced by the sound source.

Timber or quality of sound, doesn't mean a bad or good sound. It only refers to the difference in sound note produced by different sound sources.

Examples, violin has a different timber as compared to guitar.

Match the items in column A with those in column B

A

- 46. Echo
- 47. Pitch
- 48. Timber
- 49. Loudness

B

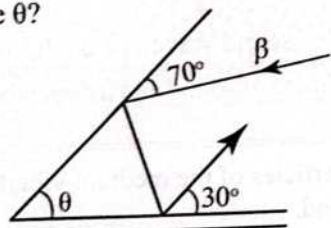
- A) Reflection of sound
- B) Amplitude of sound
- C) Frequency of sound
- D) Quality of sound
- E) Refraction of sound

Answers

46.A 47.C 48.D 49.B

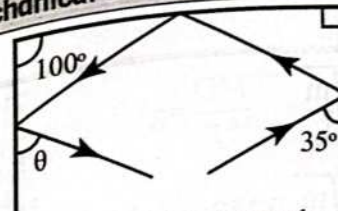
Illustrative Examples

50. If a ray of light is reflected by two mirrors as shown below, what is the value of angle θ ?



Hint: using law of reflection and interior angle sum of a triangle,
 $\theta = 80^\circ$

51. A ray of light is reflected by three mirrors as shown what is the value of angle θ ?



Hint: Use law of reflection and interior angle sum, $\theta = 25^\circ$

52. By what factor must the length of a simple pendulum be changed in order to double its period of oscillation?

A) 2

B) 1/2

C) 4

D) 1/4

Solution:

$$T_1 = 2\pi \sqrt{\frac{l_1}{g}}$$

$$T_2 = 2\pi \sqrt{\frac{l_2}{g}}, T_2 = 2T_1$$

$$\frac{T_2}{T_1} = \sqrt{\frac{l_2}{l_1}} \Rightarrow \frac{2T_1}{T_1} = \sqrt{\frac{l_2}{l_1}}$$

$$2 = \sqrt{\frac{l_2}{l_1}}$$

$$4 = \frac{l_2}{l_1} = l_2 \Rightarrow 4l_1$$

Answer: C

53. The period of a mass-spring system is 5 second. If the spring is cut into four equal parts and the mass is suspended on one of the parts, the period will be?

A) 5 sec

B) 2.5 sec

C) 1.2sec

D) 10sec

Solution:

$$T_1 = 2\pi \sqrt{\frac{m}{k_1}}$$

$$T_2 = 2\pi \sqrt{\frac{m}{k_2}}, k_2 = 4k_1$$

$$\frac{T_2}{T_1} = \sqrt{\frac{k_1}{k_2}} \Rightarrow \frac{T_2}{5} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

$$T_2 = \frac{5}{2} = 2.5 \text{ sec}$$

Answer: B

54. If the period of oscillation of mass M on a spring is 1 sec, the period of $4M$ will be

A) 2sec

B) 0.5sec

C) 4sec

D) 0.25sec

$$T_1 = 2\pi \sqrt{\frac{m_1}{k}}$$

$$T_2 = 2\pi \sqrt{\frac{m_2}{k}}, m_2 = 4m_1$$

$$\frac{T_2}{T_1} = \sqrt{\frac{m_2}{m_1}} = \sqrt{\frac{4}{1}}$$

$$T_2 = 2 \text{ sec}$$

Answer: A

55. What will be the period of oscillation of a pendulum on a planet whose mass and diameter are twice that of the earth? Assume its period is 1 sec on earth.

A) $\frac{1}{\sqrt{2}}$ secB) $\sqrt{2}$ sec

C) 2 sec

D) $\frac{1}{2}$ sec

Solution:

$$T = 2\pi \sqrt{\frac{l}{g}}, \quad g = \frac{GM}{R^2}$$

$$g_{\text{planet}} = \frac{GM_{\text{planet}}}{R_{\text{planet}}^2}, M_{\text{planet}} = 2M, R_{\text{planet}} = 2R$$

$$g_{\text{planet}} = \frac{GM_{\text{planet}}}{R_{\text{planet}}^2}, \frac{1}{2} \left(\frac{GM}{R^2} \right) = \frac{1}{2} g$$

$$T_{\text{planet}} = 2\pi \sqrt{\frac{l}{g_{\text{planet}}}} = 2\pi \sqrt{\frac{l}{\frac{1}{2}g}} = \sqrt{2} \left(2\pi \frac{\ell}{g} \right)$$

$$T_{\text{planet}} = \sqrt{2} T = (\sqrt{2})(1)$$

$$= \sqrt{2} \text{ sec}$$

Answer: B

56. Which wave phenomena is demonstrated with the diagram shown below?

A. Reflection

B. Refraction

C. Diffraction

D. Interference



Hint: The spreading out of a wave through a narrow gap is known as diffraction.

Answer: C

57. The pitch of a sound depends on?

A) Frequency

B) Amplitude

C) Wavelength

D) Speed

Hint: Pitch of sound depends on frequency, the larger the frequency, the higher the pitch.

58. The loudness of a sound depends on ?

A) Frequency

C) Wavelength

B) Amplitude

D) Speed

Hint: The loudness of a sound depends on amplitude of the sound wave. The bigger the amplitude, the louder the sound.

59. As the speed of a wave decrease, its wavelength also will decrease. Then, the frequency of the wave will

A) Decrease

C) Remain constant

B) Increase

D) Increase and then decrease

Hint: $f = \frac{v}{\lambda}$ Frequency of wave remains constant

60. Which of the following term tells us the maximum displacement of a particle from its rest position.

A) Frequency

C) Wavelength

B) Period

D) Amplitude

Hint: Maximum displacement of a particle from its equilibrium position is called amplitude.

61. The spreading out of a wave through a narrow gap or around sharp edge is known as?

A) Reflection

C) Diffraction

B) Refraction

D) Interference

62. The change in direction of a wave as it move from one medium to the

other is known as?

A) Reflection

B) Refraction

C) Diffraction

D) Interference

Answer: B

63. An elephant is calling her mate that is 476m away with a frequency of 5Hz. How many cycles of sound wave are there between the two animals, Assuming the speed of sound in air is 340m/s.

A) 5

B) 6

C) 7

D) 8

Solution:

$$\lambda = \frac{v}{f} = \frac{340}{5} = 68\text{m}$$

$$\text{Number of cycles} = \frac{s}{\lambda} = \frac{476}{68} = 7$$

Answer: C

64. All electromagnetic waves travel with the same speed in

A) Air

B) Water

C) Metal

D) Vacuum

Hint: Electromagnetic waves travel at a speed of $3 \times 10^8 \text{m/s}$ in vacuum.

Answer: D

65. Infra-sound refers to a sound wave of frequency

A) Lower than 20Hz

C) Equal to 20Hz

B) Greater than 20,000Hz

D) Equal to 20,000Hz

Answer: A

66. Ultrasound refers to a sound wave of frequency

A) Lower than 20Hz

C) Equal to 20Hz

B) Greater than 20,000Hz

D) Equal to 20,000Hz

Answer: B

67. The audible ranges of frequency for the normal human ear is?

A) Between 20Hz and 200Hz

B) Between 20Hz and 2000Hz

C) Between 20Hz and 20,000Hz

D) Between 20Hz and 200,000Hz

68. What causes an echo?

A) Refraction

B) Diffraction

C) Reflection

D) Interference

Hint: Reflection of sound from hard surface such as wall, mountain, building,,,etc...is called an echo.

69. Sound moves fastest in

A) Gas

B) Liquid

C) Solid

D) Critical fluid

70. Unlike sound wave, light wave can travel through

A) Air

B) Water

C) Vacuum

D) Metal

Hint: Sound wave is mechanical wave, while, light wave is electromagnetic.

71. What happens to a duck floating on sea water as a pulse of water passes past her?

A) It moves back and forth

C) It remains at rest

B) It moves, forward

D) It moves up and down

Hint: Since the water wave is transverse, the duck oscillates up and down

72. As a wave moves through a medium, the particles of the medium will

A) Move with the wave

B) Move in opposite direction

C) Oscillate about their rest position

D) Move out of the medium

Hint: Wave can not transport particle of a medium.

Answer: C

73. Which wave characteristic change during refraction

A) Frequency and wave length

B) Speed and frequency

C) Speed and wavelength

D) Speed, frequency and wavelength

Hint: During refraction, frequency of the wave remains constant..

Answer: C

74. When the frequency of a wave is halved, its period will be?

A) Halved

B) Doubled

C) Quartered

D) Unchanged

Hint:

$$T_1 = \frac{1}{f_1}, T_2 = \frac{1}{f_2}$$

$$f_2 = \frac{f_1}{2}$$

$$T_2 = \frac{1}{\left(\frac{f_1}{2}\right)} = 2\left(\frac{1}{f_1}\right) = 2T_1$$

Answer: B

75. If the speed of an electromagnetic wave is C and its wavelength is λ in Vacuum, and if it is moving at 0.5c in a Liquid, what will be its wavelength in the liquid?A) λ B) 0.75λ C) 0.5λ D) 0.95λ

Hint:

$$v = \lambda f \Rightarrow \lambda = \frac{v}{f}$$

$$\lambda = \frac{c}{f}$$

$$\lambda' = \frac{v'}{f} = \frac{0.5c}{f}$$

$$= 0.5\lambda$$

Answer: C

76. The turning back of a waves in to its initial medium is?

- A) Reflection
B) Refraction
C) Diffraction
D) Interference

Hint: The bouncing of a wave into the original medium from a smooth, polished and hard surface is called reflection.

Answer: A

77. The mixing up of two waves of the same type is known as?

- A) Reflection
B) Refraction
C) Diffraction
D) Interference

Hint: The overlap between two waves of the same type is known as Interference

Answer: D

78. The most infuencial factor for interfrene pattern to be constructive or destructive is?

- A) Phase B) Speed C) Frequency D) Wavelength

Hint: Being in phase or out of phase determines the interference type

Answer: A

79. Which of the following is not true about mechanical waves.

- A) They need medium
B) They transport energy
C) They travel through vacuum
D) They can be longitudinal or transverse

Hint: Mechanical waves can not pass through vacuum.

Answer: C

80. When a transverse wave move toward east, its particle will vibrate

towards:

- A) East
B) West

C) North and South

D) East and West

Hint: In a transverse wave, direction of wave motion and particles disturbance is perpendicular.

Answer: C

81. When a longitudinal wave move toward east, its particles will vibrate towards:

- A) East
B) West

C) North and South

D) East and West

Hint: In a longitudinal wave, direction of wave motion and direction of particles disturbance is parallel or anti-parallel.

Answer: D

82. What type of wave represents the back and forth, sway of crops as a wind blows across a field of grains?

- A) Helical
B) Transverse

C) Longitudinal

D) Spherical

Hint: The crops sway back and forth in the wind direction:

Answer: C

83. Which of the following is a unique property of electromagnetic waves?

- A) They travel through vacuum
B) They are transverse waves
C) They travel through medium
D) Their speed is always $3 \times 10^8 \text{ m/s}$

Hint: Electromagnetic waves have a speed of $3 \times 10^8 \text{ m/s}$ in vacuum.

Answer: A

84. Constructive interference occurs when two waves move in

- A) Opposite direction, in phase

- B) Same direction, out of phase
C) Opposite direction, out of phase
D) Same direction, in phase

Hint: For constructive interference, the mixing waves should be coherent.
Answer: D

85. When sound travels from air to water, it

- A) Continuous with the same speed
B) Travels faster
C) Stops suddenly
D) Travels slower

Hint: Speed of increases as the medium density increases
Answer: B

86. Frequency of a wave is the

- A) Distance between identical points
B) Distance moved in one second
C) Time taken to move one cycle
D) Number of cycles moved per second

Hint: $\text{frequency} = \frac{\text{cycle}}{\text{Time}}$
Answer: D

87. How many times a minute will a boat bob up and down on ocean wave that has a wavelength of 30m and 5m/s speed?

- A) 10 B) 6 C) 12 D) 36

Hint: $f = \frac{v}{\lambda} = \frac{5}{30} = \frac{1}{6} \text{ Hz}$

in one minute, the frequency is $\left(\frac{1}{6}\right)(60) = 10$ **Answer: A**

88. The distance between two adjacent crests in a pond is 0.4m. If six crests pass a point every second without considering the reference crest, what is the speed of the wave?

- A) 1.2 m/s B) 2.4m/s C) 4.8m/s D) 6.4m/s

Hint: $v = \lambda f = (0.4)(6) = 2.4\text{m/s}$

Answer: B

89. All of the following are applications of microwaves Except?
A) Sonar
B) TV signal
Hint: Sonar uses sound wave

- C) Cell phone
D) FM radio

Answer: A

90. Which physical quantities decrease as sound travels from water to air?
A) Speed and frequency
B) Wavelength and speed
Hint: Speed of sound decreases as it moves from water to air

- C) Frequency and wavelength
D) Frequency and period

Answer: B

91. The property of sound wave is related to loudness is?

- A) Wavelength B) Pitch C) Intensity D) Speed

Hint: A louder sound has bigger amplitude and intensity.
Answer: C

92. What is the period of a wave of frequency 4000 Hz?

- A) 0.25sec C) 0.00025sec
B) 0.0025sec D) 2.5 sec

Hint: $T = \frac{1}{f} = \frac{1}{4000} = 0.00025 \text{ sec}$

Answer: C

93. A radio station has a frequency of 1500 kHz . What is the wavelength?

- A) 200m B) 20m C) 100m D) 50m

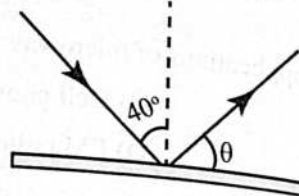
Hint: $T = \frac{1}{f} = \frac{1}{4000} = 0.00025 \text{ sec}$

Answer: A

94. The value of θ is ?

- A) 50° B) 40° C) 30° D) 90°

Hint: Use the law of reflection, $\theta = 50^\circ$



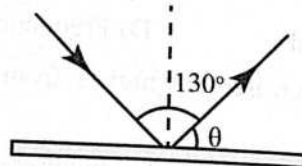
95. The value of θ

A) 65°

B) 25°

C) 75°

Hint: use the law of reflection, $\theta = 25^\circ$



96. A ship is sailing on a sea 600m above the seabed. How long will it take a pulse of sound to echo back to the ship assuming the speed of sound in sea water is 1500m/s

A) 0.8 second

C) 0.4 seconds

B) 8 seconds

D) 4 seconds

Hint: $t = \frac{2s}{v} = \frac{2(600)}{1500} = 0.8 \text{ second}$

End of Unit Questions and Problems

I. End of Unit Questions

1. What is oscillation?
2. What is wave?
3. What is Mechanical wave?
4. What is Electromagnetic wave?
5. What is Transverse wave?
6. What is Longitudinal wave?
7. What is Standing wave?

What are the properties of all waves?

What is Sound wave?

What is an Echo?

What is Pitch of sound?

What is timber of sound?

II. End of Unit Problems

13. What is frequency of an electromagnetic wave of wavelength 10 nm?

14. A simple pendulum of string length 30cm is oscillating at place where the acceleration due to gravity is 1.2m/s^2 . What is the pendulum

a) Period of oscillation

b) Frequency of oscillation

15. A mass of 2kg is oscillating at the end of a spring of stiffness 800N/m.

a) Period of oscillation

b) Frequency of oscillation

16. What is the speed of sound in a steel rod if it takes only 0.0008second to travel 4m through it?

17. What is the speed of sound in air at 30°C ?

18. A boy standing in front of cliff claps his hands and hears the echo after 2seconds. How far is the cliff from the boy? ($V=340\text{m/s}$)

19. How long will it take the sonar to detect a pulse of sound sent by a ship that is 500m above the seabed if the speed of sound in sea water is 1500m/s?

20. What is the period of a wave with a frequency of 2Hz?

21. Two identical waves of amplitude 4cm meet. What will be the extreme amplitude of the resultant wave at a point where the interference is

a) Constructive

b) Destructive

22. What is the speed of sound in a liquid whose density is $10,000\text{kg/m}^3$ and whose bulk modulus is $4 \times 10^{10}\text{Pa}$?

Short Answer to the End of Unit Questions

1. Oscillation is a periodic here and there, up and down or to and fro repeated motion of a body about its mean position?

2. Wave is a continuous disturbance of particles or fields that propagate from point to point carrying energy.
3. Mechanical wave is a wave that requires material medium for its production and propagation.

Example, Sound wave.

4. Electromagnetic wave is a wave that can travel through medium and vacuum. **Example, Light wave.**
5. Transverse wave is a wave in which the direction of wave motion is at right angle to the direction of particles vibration. **Example, String wave**

6. Longitudinal wave is a wave in which the direction of disturbance is parallel to the direction of wave motion

Example, Sound wave

7. Standing wave is a wave formed when two waves of the same type moving in opposite directions mix-up.
8. Reflection, refraction diffraction and interference are common properties of all waves.
9. Sound wave is a mechanical longitudinal wave created from a vibrating body.
10. Echo is the reflection of sound from a hard surface.
11. Pitch is the lowness or highness of sound and depend on its frequency
12. Timber is the quality of sound notes depending on its source

Solution to End of Unit Problem

$$13. v = \lambda f$$

$$f = \frac{v}{\lambda} = \frac{3 \times 10^8}{10 \times 10^{-9}} = 3 \times 10^{16} \text{ Hz}$$

$$14. A. T = 2\pi \sqrt{\frac{l}{g}}$$

$$T = 2\pi \sqrt{\frac{0.3}{1.2}} = 3.14 \text{ second}$$

$$B. f = \frac{1}{T} = \frac{1}{3.14}$$

$$f = 0.318 \text{ Hz}$$

$$15. A. T = 2\pi \sqrt{\frac{m}{k}} = 2\pi$$

$$T = \sqrt{\frac{2}{800}} = 0.314 \text{ sec}$$

$$B. f = \frac{1}{T} = \frac{1}{0.314}$$

$$f = 3.18 \text{ Hz}$$

$$16. v = \frac{s}{t} = \frac{4}{0.0008}$$

$$v = 5000 \text{ m/s}$$

$$17. v = 331 + 0.6T$$

$$v = 331 + 0.6T$$

$$= 349 \text{ m/s}$$

$$18. s = \frac{vt}{2}$$

$$s = \frac{(340)(2)}{2} = 340 \text{ m}$$

$$19. s = \frac{vt}{2} \Rightarrow t = \frac{2s}{v}$$

$$t = \frac{2(500)}{1500} = 0.67 \text{ second}$$

20.

$$T = \frac{1}{f}$$

$$T = \frac{1}{2} = 0.5 \text{ second}$$

$$\text{A. } a = a_1 + a_2$$

$$21. \quad a = 4 + 4 = 8 \text{ m}$$

$$\text{B. } a = a_1 - a_2$$

$$a = 4 - 4 = 0 \text{ m}$$

$$22. \quad v = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{4 \times 10^{10}}{1^4 0}}$$

$$= 2 \times 10^3 \text{ m/a}$$

UNIT 7

7. Temperature and Thermometry

7.1 Temperature and Our Life

7.2 Temperature Scales

7.3 Types of Thermometers

7.4 Thermal Expansion of Materials

7. Temperature and Thermometry

Hello there! We are very glad to meet you in this fascinating unit where you will be able to; define temperature, explain types of temperature scales, list types of thermometers and solve problems related to temperature scales conversion and linear expansion of materials. You will love and enjoy it!

7.1 Temperature and Our Life

Usually, temperature is described as the measure of the degree of hotness and coldness of a body.

However, this description is not reliable since it depends on individuals sensitivity to hot and cold. Therefore, the formal definition of temperature is the following

Temperature: Is the measure of average kinetic energy of particles of a body.

- ✓ A body is said to have high temperature if its particles average kinetic energy is large and low temperature if its particles have small kinetic energy.

Temperature is a scalar quantity and its SI Unit is the Kelvin(k).

Other units of temperature are degree Celsius ($^{\circ}\text{C}$) and degree Fahrenheit ($^{\circ}\text{F}$)

In nature, temperature has wide ranges. From very high sun's outer surface temperature of about 5500°C to the very low liquid nitrogen temperature of -196°C . What is more, on the earth surface, it varies from about 30°C on the equatorial zone to about -40°C on the polar zone.

- ✓ On the average, the normal human body temperature to be about 37°C the surrounding environment needs to be about 28°C .

Conceptual Examples

1. What is room temperature? Explain.

Explanation:

Room temperature is a temperature in the range of 18°C to 22°C with

which human are comfortable.

2. What is extreme temperature? Explain.

Explanation:

Extreme temperature is a temperature which is too high or too low from the room temperature.

3. What is Greenhouse effect? Explain

Explanation:

Greenhouse effect is the warming of the earth when atmospheric gases such as carbon dioxide, methane, nitrous oxide, water vapor and fluorinated gases trap heat from the sun.

4. What is global warming? Explain.

Explanation:

Global warming is the increase in the temperature of the world as a whole.

5. What is the cause of global warming? Explain.

Explanation:

Global warming is caused mainly by the burning of fossil fuels, natural gas, coal, etc. by humans in an attempt to generate energy.

6. What are the effects of extreme temperature? Explain.

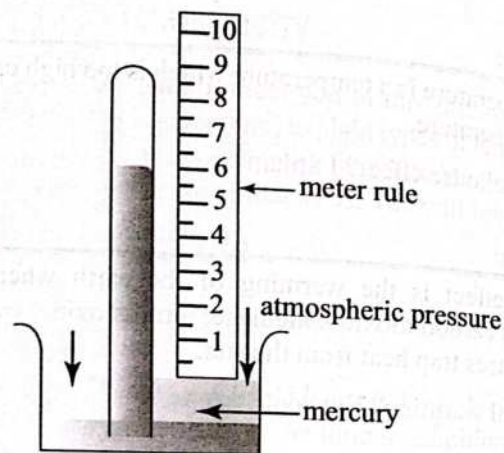
Explanation:

Too low temperature causes snow and ice and death to plants and animals. Too high temperature causes draught, desert, famine and death to animals and plants and rivers, lakes and other water resource will dry.

- ✓ Higher temperature causes heat waves and leads to heat cramps and heat stroke and death.

The device that is used to measure temperature of a body is called Thermometer.

A typical thermometer is a cylindrical tube with a small bulb at its base, and filled with mercury or alcohol to a certain height. Parts of a mercury thermometer are shown below.



A typical mercury Thermometer

Conceptual Example

7. How do the Mercury and Alcohol thermometer work? Explain.

Explanation:

They do work by expansion and contraction that is rising or falling through the tube when the temperature changes.

8. Mercury thermometer may not be used at temperature below -40°C . Why?

Explanation:

This is because, mercury freezes and changes to solid at this temperature.

7.2 Temperature Scales

The most common temperature scales are three. Those are centigrade or Celsius, Fahrenheit and Kelvin scales. And, in designing typical thermometers, two points are marked on it. The lower fixed point and the upper fixed point.

- ✓ The lower fixed point, LFP is the freezing, ice or melting point of water, and upper fixed point, UFP is the steam or boiling point of water.
- Now, let us go through the three temperature scales one by one.

The Celsius Scale

This scale, the Celsius is also called the *Centigrade scale* and was developed by Anders Celsius. He assigned 0°C to the ice point of water and 100°C to the boiling point of water.

- ✓ This scale has 100 equal divisions.

The Fahrenheit Scale

It was developed by Daniel Fahrenheit. He assigned 32°F to the ice point of water and 212°F to the boiling point of water.

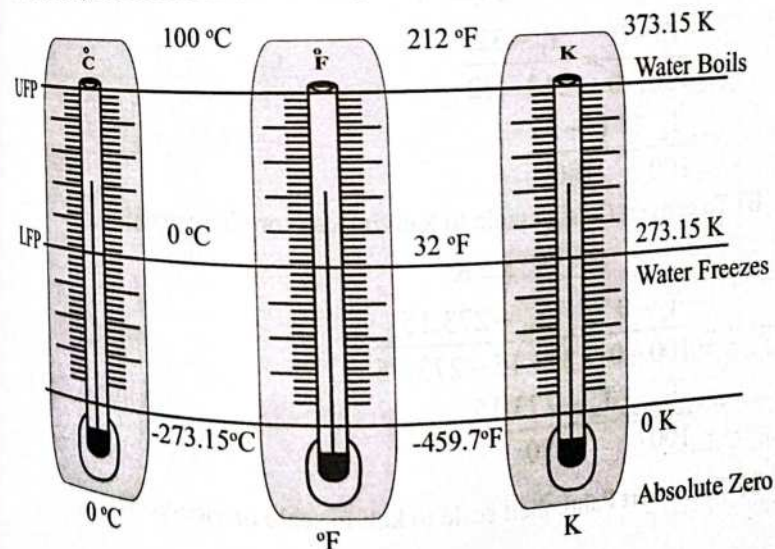
- ✓ This scale has 180 equal divisions.

The Kelvin Scale

It was developed by Lord Kelvin. He assigned 273.15K to the ice point of water and 373.15K to the boiling point of water.

- ✓ This scale has 100 equal divisions.

The three scales with their lower and upper fixed points are shown using the mercury thermometer as follows,



Absolute Zero: Is the temperature at which particles stop movement and the body will not have thermal energy.

$$\text{Absolute Zero } 0\text{K} = -273.15^{\circ}\text{C}$$

Conversion Between Temperature Scales

To convert temperature scale x to temperature scale y or vice-versa, use the following relation

$$x \rightleftharpoons y$$

$$\frac{T_x - T_{x(\text{ice})}}{T_{x(\text{boiling})} - T_{x(\text{ice})}} = \frac{T_y - T_{y(\text{ice})}}{T_{y(\text{boiling})} - T_{y(\text{ice})}}$$

Or

$$\frac{T_x - T_{x(\text{LFP})}}{T_{x(\text{UFP})} - T_{x(\text{LFP})}} = \frac{T_y - T_{y(\text{LFP})}}{T_{y(\text{UFP})} - T_{y(\text{LFP})}}$$

Using the above relations, We can have the following specific cases

A) To convert Celsius scale to Fahrenheit scale or vice-versa

$$^{\circ}\text{C} \rightleftharpoons ^{\circ}\text{F}$$

$$\frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32}$$

$$\frac{T_C}{100} = \frac{T_F - 32}{180}$$

B) To convert Celsius scale to Kelvin scale or vice-versa

$$^{\circ}\text{C} \rightleftharpoons \text{K}$$

$$\frac{T_c - 0}{100 - 0} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_C}{100} = \frac{T_K - 273.15}{180}$$

C) To convert Fahrenheit scale to kelvin scale or vice-versa

$$^{\circ}\text{F} \rightleftharpoons \text{K}$$

$$\frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

Illustrative Examples

9. Convert 50°F in to

a) $^{\circ}\text{C}$

b) K

Solution:

$$\text{a) } \frac{T_F - 32}{212 - 32} = \frac{T_C - 0}{100 - 0}$$

$$\frac{T_F - 32}{180} = \frac{T_C}{100}$$

$$\frac{50 - 32}{180} = \frac{T_C}{100}$$

$$T_C = 20^{\circ}\text{C}$$

$$\text{b) } \frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$$

$$\frac{50 - 32}{180} = \frac{T_K - 273.15}{100}$$

$$T_K = 283.15\text{K}$$

10. Convert 20°C into

a) $^{\circ}\text{C}$

b) K

Solution:

$$a) \frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32}$$

$$\frac{T_C}{100} = \frac{T_F - 32}{180}$$

$$\frac{20}{180} = \frac{T_F - 32}{180} = 68^\circ\text{F}$$

$$T_F = 68^\circ\text{F}$$

$$b) \frac{T_C - 0}{100 - 0} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\frac{T_C}{100} = \frac{T_K - 273.15}{100}$$

$$\frac{20}{180} = \frac{T_K - 273.15}{100} = 293.15\text{K}$$

$$T_K = 293.15\text{K}$$

11. Convert 573.15k into

a) $^\circ\text{C}$ b) $^\circ\text{F}$ *Solution:*

$$a) \frac{T_K - 273.15}{373.15 - 273.15} = \frac{T_C - 0}{100 - 0}$$

$$\frac{T_K - 273.15}{100} = \frac{T_C}{100}$$

$$\frac{573.15 - 273.15}{100} = \frac{T_C}{100}$$

$$T_C = 200^\circ\text{C}$$

$$\frac{T_K - 273.15}{373.15 - 273.15} = \frac{T_F - 32}{212 - 32}$$

$$\frac{573.15 - 273.15}{100} = \frac{T_F - 32}{180}$$

$$\frac{573.15 - 273.15}{100} = \frac{T_F - 32}{180} = 392^\circ\text{F}$$

$$T_F = 392^\circ\text{F}$$

12. An unknown thermometer x has a boiling point of 312° and an ice point of 112° . If a body temperature is found to be 28°C , what will be this value with temperature scale x?

Solution:

$$\frac{T_C - 0}{100 - 0} = \frac{T_x - 112}{312 - 112}$$

$$\frac{T_C}{100} = \frac{T_x - 112}{200} = 168^\circ$$

$$T_x = 168^\circ$$

13. At what temperature will they read the same

a) $^\circ\text{C}$ and $^\circ\text{F}$ b) $^\circ\text{C}$ andc) $^\circ\text{F}$ and*Solution:*

$$a) \frac{T_C - 0}{100 - 0} = \frac{T_F - 32}{212 - 32}$$

$$\text{let } T_C = T_F = T$$

$$\frac{T}{100} = \frac{T - 32}{180} = -40^\circ$$

$$T_C = T_F \text{ at } -40^\circ$$

$$b) \frac{T_F - 32}{212 - 32} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\text{let } T_F = T_K = T$$

$$T = 574.6^\circ$$

$$c) \frac{T_C - 0}{100 - 0} = \frac{T_K - 273.15}{373.15 - 273.15}$$

$$\text{let } T_C = T_K = T$$

$$\frac{T}{100} = \frac{T - 273.15}{100}$$

They never read the same

14. A sample of gas cools from -120°C to -180°C . What is the change in temperature in

- Kelvin scale
- Fahrenheit scale

Solution:

$$a) \frac{T_{C1} - 0}{100 - 0} = \frac{T_{K1} - 273.15}{373.15 - 273.15}$$

$$\frac{-120 - 0}{100} = \frac{T_{K1} - 273.15}{100}$$

$$T_{K1} = 153.15\text{K}$$

$$\frac{T_{C2} - 0}{100 - 0} = \frac{T_{K2} - 273.15}{373.15 - 273.15}$$

$$\frac{-180}{100} = \frac{T_{K2} - 273.15}{100}$$

$$T_{K2} = 93.15\text{K}$$

$$\Delta T_K = T_{K2} - T_{K1} = 93.15 - 153.15 = -60\text{K}$$

$$b) \frac{T_{C1} - 0}{100 - 0} = \frac{T_{F1} - 32}{212 - 32}$$

$$\frac{-120}{100} = \frac{T_{F1} - 32}{180} = -184^\circ\text{F}$$

$$T_{F1} = 184^\circ\text{F}$$

$$\frac{T_{C2} - 0}{100 - 0} = \frac{T_{F2} - 32}{212 - 32}$$

$$\frac{-180}{100} = \frac{T_{F2} - 32}{180} = -292^\circ\text{F}$$

$$T_{F2} = 292^\circ\text{F}$$

$$\Delta T_K = T_{F2} - T_{F1} = -292 - (-184) = -108^\circ\text{F}$$

15. If the change in temperature is found to be 25°C , what will be this value in

- K
- $^\circ\text{F}$

Solution:

$$a) \frac{T_{C1} - 0}{100 - 0} = \frac{T_{K1} - 273.15}{373.15 - 273.15}$$

$$\frac{T_{C1}}{100} = \frac{T_{K1} - 273.15}{100}$$

$$T_{C1} = T_{K1} - 273.15$$

$$\frac{T_{C2} - 0}{100 - 0} = \frac{T_{K2} - 273.15}{373.15 - 273.15}$$

$$T_{C2} = T_{K2} - 273.15$$

$$\Delta T_C = T_{C2} - T_{C1} = 25^\circ\text{C}$$

$$\Delta T_K = T_{K2} - T_{K1} = 25\text{K}$$

$$b) \frac{T_{C1} - 0}{100 - 0} = \frac{T_{F1} - 32}{212 - 32}$$

$$\frac{T_{C1}}{100} = \frac{T_{F1} - 32}{180}$$

$$T_{C1} = \frac{5}{9}(T_{F1} - 32)$$

$$T_{C2} = \frac{5}{9}(T_{F2} - 32)$$

$$\Delta T_C = T_{C2} - T_{C1} = \frac{5}{9}[(T_{F2} - 32) - (T_{F1} - 32)]$$

$$25 = \frac{5}{9} \Delta T_F$$

$$\Delta T_F = 45^\circ F$$

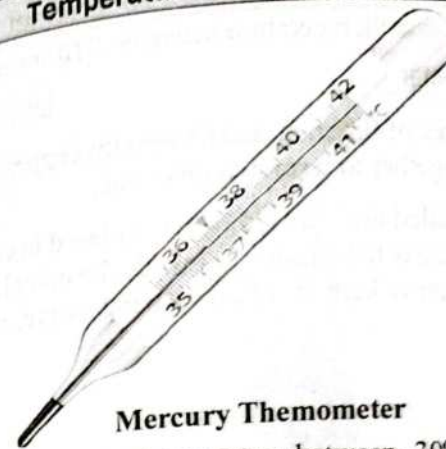
- ✓ The change in temperature in the Celsius scale is the same as the change in temperature of the Kelvin scale.

7.3 What are the Types of Thermometers?

For their operation, most thermometers make use of a change in physical property with a change in temperature. For example, the thermometric property of mercury thermometer is the length of mercury column and that of a constant volume gas thermometer is the pressure of the gas. Now, let us be familiar with some of the thermometer types.

Mercury Thermometer

Is a tube filled with mercury and a standard temperature scale is marked on it. With a change in temperature, the mercury expands and contracts, so that the temperature of a body can be read from the scale.

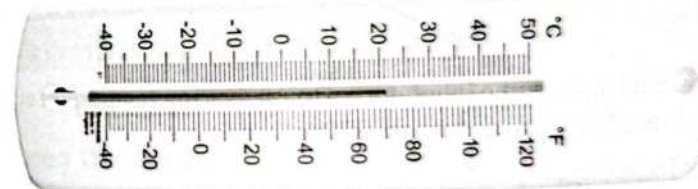


Mercury Thermometer

- ✓ It is used to measure temperature between $-30^\circ C$ and $300^\circ C$.

Alcohol Thermometer

Makes use of the expansion and contraction of alcohol such as ethanol in response to a change in temperature.

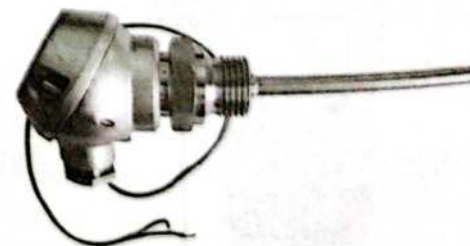


Alcohol Thermometer

- ✓ It is used to measure temperature between $-115^\circ C$ and $78.15^\circ C$

Resistance Thermometer

It uses the change in resistance of materials such as platinum to measure temperature of a body.



- ✓ It is used to measure temperature between -270°C and 700°C

Thermocouple Thermometer

It consists of thin wires of different metals usually copper and, a copper-nickel alloy welded together to form two junctions.

One of the junction, called the 'hot' junction is placed in contact with the body whose temperature is to be measured while the other junction, called the 'reference' junction is kept at a known temperature, usually an ice-water mixture at 0°C .



- ✓ It is used in scientific laboratories to measuring temperature as high as 2300°C and as low as -270°C

Thermistor Thermometer

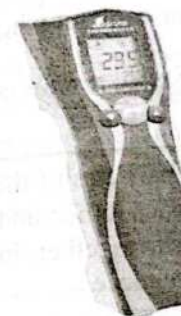
It uses the change in resistance of metallic oxide when temperature changes. It is of two types: negative temperature coefficient, with low resistance at high temperature and positive temperature coefficient, with high resistance at high temperature.



- It has precision with in a temperature range of 50°C .

Radiation Thermometer

It uses electromagnetic radiation of a body whose temperature is to be measured



- ✓ It is used in hospitals and in glass and electrical industries to check the temperature of components of a motor or machine.

Illustrative Examples

Match the items in column 'A' with those in column 'B'

Column A

16. Mercury Thermometer
17. Alcohol Thermometer
18. Resistance Thermometer
19. Thermocouple Thermometer
20. $^{\circ}\text{C}$
21. $^{\circ}\text{F}$
22. K

Column B

- a) Andres Celsius
- b) Daniel Fahrenheit
- c) Lord Kelvin
- d) -30°C to 300°C
- e) -115°C to 78.15°C
- f) -270°C to 700°C
- g) -270°C to 2300°C
- h) -295°C to $10,00^{\circ}\text{C}$

Answers

- 16.d 17.e 18.f 19.g 20.a 21.b 22.c

7.4 Thermal Expansion of Materials

Most materials expand when heated and contract when cooled.

Conceptual Examples

23. Why do materials expand or contract when the temperature changes? Explain.

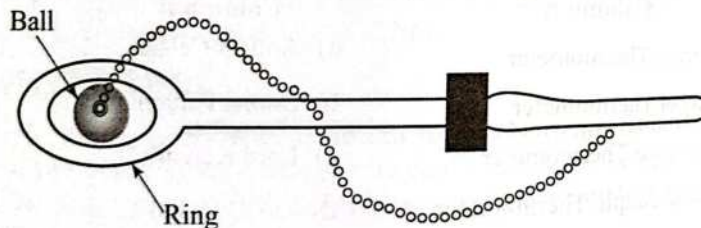
Explanation:

Because, when heated, the particles of the body gain more energy and move further apart from each other and when cooled, the particles lose energy and come closer together, in this manner, expansion and contraction of materials take place.

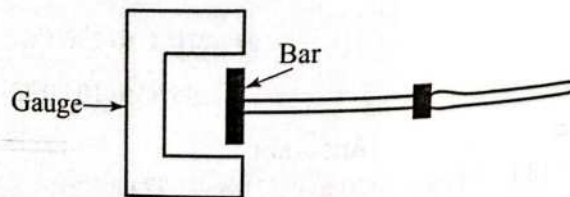
Thermal Expansion: Is the increase in size of a body when heated.

When a body is heated, its particles move further apart and its size increases.

The ball and ring experiment is a good demonstration of expansion of a material. The cold metal ball easily pass through the ring. After heating, the ball expands and it is no longer able to pass through the ring.



In the same manner, the metal bar will just fit into the gap in the gauge when both the bar and the gauge are cold.



In general, when a material is heated, its expansion can be one dimensional - linear, two dimensional - area or three dimensional - volume. In this level

however, we will only describe linear expansion.

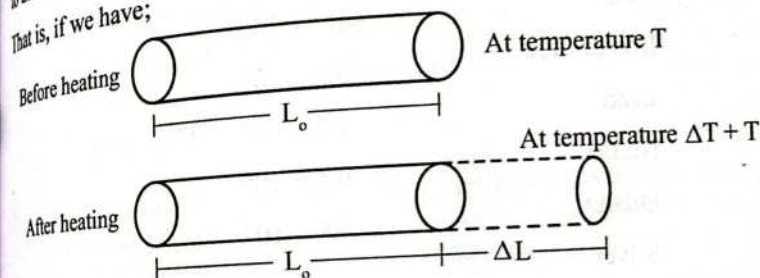
Linear Expansion of Materials

When a metal rod is heated, it expands and increase in length. This type of expansion is called *linear expansion*.

Linear Expansion: Is the increase in length of a rod due to heating.

The expansion, that is the increment or the change in length, ΔL of a rod of initial length L_0 at a temperature of T is found to be directly proportional to the original length and the change in temperature, ΔT .

That is, if we have;



Then, it is observed experimentally that:

$$\Delta L \sim L_0, \text{ and } \Delta L \sim \Delta T$$

Hence, $\Delta L \sim L_0 \Delta T$

$$\Delta L = \alpha L_0 \Delta T$$

Where: α (alpha) is called coefficient of linear expansion and its unit is per Kelvin (K^{-1}) or per Celsius ($^{\circ}C^{-1}$)

The total length of the rod after heating is obtained by,

$$L = L_0 + \Delta L$$

$$= L_0 + \alpha L_0 \Delta T$$

$$L = L_0 [1 + \alpha \Delta T]$$

✓ Different materials expand or contract at different rates and hence they have different coefficients of thermal expansion. The coefficient of linear expansion of some solids is given below.

Material	Coefficient of Linear expansion($^{\circ}\text{C}^{-1}$)
Aluminium	2.6×10^{-5}
Brass	1.9×10^{-5}
Concrete	1.2×10^{-5}
Copper	1.7×10^{-5}
Common Glass	8.3×10^{-5}
Pyrex Glass	3.3×10^{-5}
Gold	1.4×10^{-5}
Iron or Steel	1.2×10^{-5}
Lead	2.9×10^{-5}
Nickel	1.3×10^{-5}
Quartz	0.5×10^{-5}
Silver	1.9×10^{-5}

Conceptual Examples

24. The coefficient of linear expansion of steel is found to be $1.2 \times 10^{-5}^{\circ}\text{C}^{-1}$. What does this mean?

Explanation:

It means that, a 1m steel rod will expand or increase by $1.2 \times 10^{-5}\text{m}$ for every 1°C rise in temperature.

Illustrative Examples

25. A Gold rod of length 0.5m at a temperature of 30°C is heated to a temperature of 50°C . What will be the change in length after the process?

Solution:

$$\Delta L = \alpha L_0 \Delta T = (1.4 \times 10^{-5})(0.5)(50 - 30)$$

$$\Delta L = 1.4 \times 10^{-4}\text{m}$$

26. A steel rod has a length of 200cm at a temperature of 20°C . What will

be the total length of the rod at 120°C ?

Solution:

$$\begin{aligned} L &= L_0 [1 + \alpha \Delta T] \\ &= 2 [1 + (1.2 \times 10^{-5})(120 - 20)] \\ L &= 2.0024\text{m} \end{aligned}$$

27. What change in temperature is needed so as to let a 1.5 long silver rod to increase by 10cm?

Solution:

$$\Delta L = \alpha L_0 \Delta T \Rightarrow \Delta T = \frac{\Delta L}{\alpha L_0} = \frac{0.1}{(1.9 \times 10^{-5})(1.5)} = \frac{10000}{285}$$

$$\Delta T = 35^{\circ}\text{C}$$

28. At what temperature will the increase in length of a 2m brass rod at 0°C become 5.7mm

Solution:

$$\Delta L = \alpha L_0 \Delta T \Rightarrow \Delta T = \frac{\Delta L}{\alpha L_0} = \frac{5.7 \times 10^{-3}}{(1.9 \times 10^{-5})(2)} = 150$$

$$\Delta T = 150^{\circ}\text{C}$$

$$\Delta T = T_2 - T_1 = 150$$

$$T_2 - 0 = 150$$

$$T_2 = 150^{\circ}\text{C}$$

Coefficient of linear expansion is α (alpha), coefficient of volume expansion is β (beta), $\beta = 3\alpha$ and the coefficient of volume expansion is γ (gamma), $\gamma = 3\alpha$. So we have:

✓ Linear Expansion, $\Delta L = \alpha L_0 \Delta T$

✓ Area Expansion, $\Delta A = \beta A_0 \Delta T$

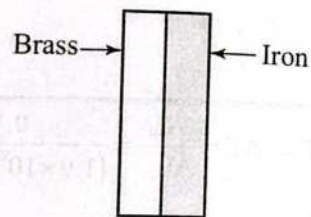
✓ Volume Expansion, $\Delta V = \gamma V_0 \Delta T$

The Bimetallic Strip

A bimetallic strip is a strip made of two metals welded together.

Bimetallic Strip: Is a strip made of two different metals bonded together along their length.

For example, if iron and brass are bonded together, since coefficient of linear expansion of iron $1.2 \times 10^{-5} \text{ } ^\circ\text{C}^{-1}$ is less than that of brass, $1.9 \times 10^{-5} \text{ } ^\circ\text{C}^{-1}$, when the strip is heated, the brass expands more than the iron and the strip bends.



A bimetallic Strip

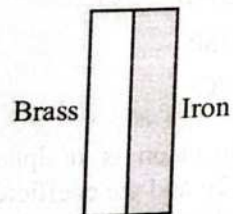
Illustrative Example

29. What will happen to a brass-iron bimetallic strip when it is

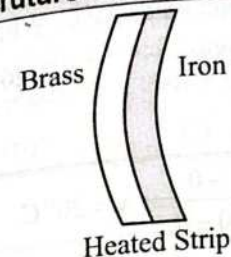
- a) Heated
- b) Cooled

Explanation:

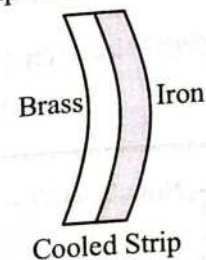
The strip is linear at a room temperature



- a) When heated, the brass expands more than the iron since it has greater coefficient of thermal expansion and the strip bends towards the iron.



- b) When cooled, the strip bends towards the brass as shown

**Additional Examples**

30. A change in temperature of 25°C is equivalent to

- A) 45°F
- B) 72°F
- C) 32°F
- D) 25°F

Solution:

$$\Delta T_F = \frac{9}{5} \Delta T_C = \frac{9}{5} (25) = 45^\circ\text{F}$$

Answer: A

31. The normal temperature of a human body is x degrees above absolute zero. What is the value of x ?

- A) 100
- B) 200
- C) 310
- D) 340

Solution:

$$T_C = 37^\circ\text{C}, \text{ and } T_K = T_C + 273$$

$$T_K = 37 + 273$$

$$T_K = 310\text{K}$$

Answer: C

32. The upper and lower fixed points of a faulty thermometer are 5°C and

105°C. If this thermometer reads 25°C, What is the actual temperature?

- A) 15°C B) 30°C C) 20°C D) 35°C

Solution:

$$\frac{25-5}{105-5} = \frac{x-0}{100-0} \Rightarrow x = 20^\circ\text{C}$$

Answer: C

33. At what temperature is the Fahrenheit scale reading equal to twice the Celsius scale reading?

- A) 160°C B) 320°C C) 175°C D) 273°C

Solution:

$$\frac{T_F - 32}{180} = \frac{T_C}{100}, \text{ Now } T_F = 2T_C$$

$$\frac{2T_C - 32}{180} = \frac{T_C}{100}$$

$$T_C = 160^\circ\text{C}$$

Answer: A

34. Which of the following temperatures is highest?

- A) 100 B) -13°F C) -20°C D) -28°C

Solution:

$$-13^\circ\text{F} = 25^\circ\text{C}, \text{ and } 100^\circ\text{C} = 212^\circ\text{F}$$

Answer: C

35. Two thermometer, one Celsius and the other of Fahrenheit scale are kept in a bath. If the Fahrenheit reads twice that of Celsius, what is temperature of the bath?

- A) 80°C B) 80°F C) 32°C D) 12°C

Solution:

$$\frac{T_F - 32}{180} = \frac{T_C}{100}, \text{ Now } T_F = 3T_C \Rightarrow T_C = \frac{T_F}{3}$$

$$\frac{T_F - 32}{180} = \frac{T_F}{300}$$

$$T_F = 80^\circ\text{F}$$

Answer: B

36. On a hypothetical scale x, the ice point is 40° and the steam point is 120°. For another scale Y, the ice point and the steam point are -30° and 130° respectively. If x reads 50°, then Y would read?

- A) -5° B) -10° C) -80° D) 12°

Solution:

$$\frac{50-40}{120-40} = \frac{y-(-30)}{130-(-30)} \Rightarrow y = -10^\circ$$

Answer: B

37. When a Celsius thermometer reads 90°C, a Fahrenheit scale will read?

- A) 124°F B) 164°F C) 120°F D) 194°F

Solution:

$$\frac{T_F - 32}{180} = \frac{90-0}{100-0} \Rightarrow 194^\circ\text{F}$$

Answer: D

38. What is the ratio of the coefficient of linear expansion to the coefficient of volume expansion?

- A) 1:2 B) 1:4 C) 1:3 D) 1:2

Solution:

$$\frac{\alpha}{\gamma} = \frac{\alpha}{3\alpha} = \frac{1}{3} = 1:3$$

Answer: C

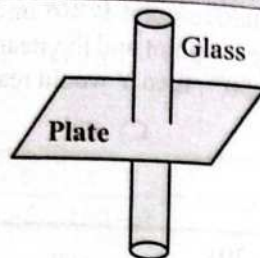
39. Thin strips of iron and zinc are riveted together to form a bimetallic strip that bends when heated. The iron is on the inside of the bend because, it has a

- A) Higher specific heat C) Lower coefficient of expansion
B) Lower specific heat D) Higher coefficient of expansion

Hint: $\alpha_{\text{iron}} = 1.2 \times 10^{-5}/^\circ\text{C}$ and $\alpha_{\text{zinc}} = 2.6 \times 10^{-5}/^\circ\text{C}$

Answer: C

40. A glass rod, $\alpha = 0.9 \times 10^{-5}/^\circ\text{C}$ is fitted into a hole of the same diameter of copper plate, $\alpha = 1.7 \times 10^{-5}/^\circ\text{C}$. What will happen when the system is heated?



- A) The plate will drop
 B) The glass will crack
 C) The plate will fold
 D) There will be no change

Hint: Since $\alpha_{\text{Cooper}} > \alpha_{\text{Glass}}$ it expands more.

41. A steel beam is 25m long in winter at 0°C . How much will the length change in summer at 30°C ? ($\alpha_{\text{Steel}} = 1.2 \times 10^{-5}/^{\circ}\text{C}$)

- A) 6mm
 B) 9mm
 C) 25mm
 D) 5mm

Solution:

$$\Delta L = \alpha L_0 \Delta T = (1.2 \times 10^{-5})(25)(30 - 0)$$

$$\Delta L = 0.009\text{m} = 9\text{mm}$$

Answer: B

End of Unit Questions and Problems

I. Give Short Answer to the Following Questions.

1. What is Temperature?
2. What is the SI unit of temperature?
3. The instrument used to measure temperature is known as _____.
4. What is Greenhouse effect?
5. What is Global warming?
6. List the most common temperature scales
7. Mention types of thermometers
8. What is the room temperature in Celsius
9. What is the average normal human body temperature in
 - A) Celsius
 - B) Fahrenheit

C) Kelvin Scale

10. What are the lower and upper fixed points represent in a thermometer scale.

11. What are the lower and upper fixed points of water in scale.

- A) Celsius
- B) Fahrenheit
- C) Kelvin Scale

12. What is the lowest possible temperature in nature?

13. What is thermal expansion?

14. What is the coefficient of linear expansion of materials?

15. Absolute zero is equivalent to _____ degree Celsius.

II. Solve the Following Problems

16. If the surrounding temperature is 82°F , What is its value in

- A) Celsius
- B) Kelvin

17. At what temperature will the Fahrenheit and Celsius scales read the same?

18. What is the temperature in Celsius if it is zero in Fahrenheit scale?

19. If the temperature of an object is 310K, what is this temperature in

- A) Celsius
- B) Fahrenheit

20. The ice and the steam points of a thermometer are found to be 25° and 125° respectively. What will this thermometer read if a body temperature is 62°C ?

21. What is the increase in length of a 2m copper rod that is heated from 20°C to 140°C ?

22. What empty space is needed to protect a 3m long concrete from 25°C to 38°C ?

23. Which one is largest? 1°C or 1°F or 1K justify your answer.

I. Short Answers and Explanations

1. Temperature is the measure of average Kinetic energy of particle of a body
2. Kelvin
3. Thermometer
4. It is the warming of the earth by the green house gases that have trapped sun's thermal energy.
5. It is the increases in temperature over all the world.
6. Celsius, Fahrenheit and Kelvin
7. Mercury, Alcohol, Resistance, Thermocouple, Thermistor, Radiant Thermometers
8. It is in the range 18°C and 22°C
9.
 - A) 37°C
 - B) 99°C
 - C) 310°C
10. Lower fixed point represents the freezing, melting or ice point of water while the upper fixed point represents the boiling or steam point of water.

Scale	LFP	UFP
$^{\circ}\text{C}$	0	100
$^{\circ}\text{F}$	32	212
K	273.15	373.15

12. It is the absolute zero. Zero Kelvin, Ok!
13. It is the increases in size of body up on heating.
14. It is the increases in length of a 1m rod of a given substance when its temperature increase by 1k.
15. Ok = -273.15°C

II. Solution to the End of Unit Problems

$$\begin{aligned} \text{A) } \frac{T_c}{100} &= \frac{82-32}{180} \Rightarrow \frac{T_c}{5} = \frac{50}{9} = 55.5^{\circ}\text{C} \\ \text{B) } \frac{T_k - 273.15}{100} &= \frac{82-32}{180} \Rightarrow \frac{T_k - 273.15}{5} = \frac{50}{9} \\ T_k &= 328.65\text{K} \end{aligned}$$

$$\begin{aligned} \frac{T_c}{100} &= \frac{T_f - 32}{180}, \text{ let } T_c = T_f = T \\ \frac{T}{5} &= \frac{T - 32}{9} \Rightarrow T = -40^{\circ}\text{C} \end{aligned}$$

$$\begin{aligned} \frac{T_c}{100} &= \frac{T_f - 32}{180} \\ \frac{T_c}{5} &= \frac{0-32}{9} \Rightarrow T_c = -15.5^{\circ}\text{C} \end{aligned}$$

$$\text{A) } \frac{T_c}{100} = \frac{310-273}{100} \Rightarrow T_c = 37^{\circ}\text{C}$$

$$\text{B) } \frac{T_f - 32}{180} = \frac{310-273}{100} \Rightarrow T_f = 99^{\circ}\text{F}$$

$$\frac{62}{100} = \frac{T_x - 25}{100} \Rightarrow T_x = 87^{\circ}$$

$$\Delta L = \alpha L_0 \Delta T = (1.7 \times 10^{-5})(2)(140 - 20) = 4.08 \times 10^{-3}\text{m} = 4.08\text{mm}$$

$$\Delta L = \alpha L_0 \Delta T = (1.2 \times 10^{-5})(3)(38 - 25) = 0.00047\text{m} = 0.47\text{mm}$$

$$1^{\circ}\text{F} = -17.2^{\circ}\text{C} \text{ and } 1\text{k} = -272.15^{\circ}\text{C}, \text{ Therefore: } 1^{\circ}\text{C} \text{ is the largest.}$$

UNIT 8

8. Elasticity and Static Equilibrium

8 . 1 Elasticity and Plasticity

8 . 2 Density and Specific Gravity

8 . 3 Stress and Strain

8 . 4 Young's and Bulk Modulus

8 . 5 Static Equilibrium

8. Elasticity and Static Equilibrium

Dear learner, you are welcome to this wonderful unit where the concepts of material properties such as elasticity, plasticity, density, specific gravity, stress, strain, young's modulus and bulk modulus are clearly defined and explained. what is more, you will also be clear about the first and the second conditions of static equilibrium Have a nice time .

8.1 Elasticity and Plasticity

When a force is exerted on a body, it may cause the body to deform and change its shape and size. And based on their tendency to restore their original shape and size. after the removal of the applied force, materials may have elasticity or plasticity property

Elasticity : Is property of a body by virtue of which it regains its original size and shape after the removal of the applied force,

And, the materials that regain their original size and shape when the deforming force is removed are called *Elastic materials*, and their deformation is called *elastic deformation*.

Spring and rubber band are examples of elastic materials.

Did You know ?

Even an elastic material will no longer behave elasticity after a stress level called an *Elastic limit* and beyond this limit, the material became plastic

Plasticity : Is property of a body by virtue of which it will not regain its original size and shape when the deforming force is removed

And, materials that do not restore their original size and shape when the applied force is removed are called **plastic materials**, and their deformation is called *plastic deformation*.

Mud and wax are examples of plastic materials.

Illustrative Example

Match the items in column 'A' with those in column 'B'

A

1. Deformation
2. Elasticity
3. Plasticity
4. Elastic material
5. Plastic material
6. Elastic deformation
7. Plastic deformation
8. Elastic limit

B

- a) Maximum stress level
- b) Reversible deformation
- c) Irreversible deformation
- d) Property to restore size and shape
- e) Property not to restore size and shape
- f) Restore their size and shape
- g) Can not restore their size and shape
- h) Change in size and shape

Answers

- | | | | |
|------|------|------|------|
| 1. h | 3. e | 5. g | 7. c |
| 2. d | 4. f | 6. b | 8. a |

8.2 Density and Specific Gravity

How particles of a body are packed together is called *density* of the body.

Density : Is the ratio of mass of the body to its volume

$$\text{Density} = \frac{\text{Mass of the body}}{\text{Volume of the body}}$$

$$\rho(\text{rho}) = \frac{m}{v}$$

Density is a scalar quantity and its SI unit is kilogram per meter cube, kg/m^3

And, some times density of a body may be given in gram per centimetre cube, g/cm^3 with the fact that, $1\text{kg/m}^3 = 10^{-3} \text{g/cm}^3$

Density is a unique physical property of a material that differentiate it from any other materials

The density of a body as compared to the density of water is called *specific gravity*.

gravity:

Specific Gravity (Relative Density) : Is the ratio of the density of a body to the density of water at 4°C

$$\text{Specific Gravity} = \frac{\text{Density of a body}}{\text{Density of water}}$$

$$\text{SG} = \frac{\rho_{\text{substance}}}{\rho_{\text{water}}}$$

Specific gravity is a unit less scalar quantity. For example, the density of gold is $19.3 \times 10^3 \text{kg/m}^3$ and its specific gravity is

$$\text{SG} = \frac{\rho_{\text{gold}}}{\rho_{\text{water}}} = \frac{19.3 \times 10^3}{10^3}$$

$$\text{SG} = 19.3$$

The density and specific gravity of some substances at 0°C and 1atm are given below

Material	Density (kg/m^3)	Specific Gravity
Air	1.29	1.29×10^{-3}
Alcohol	7.9×10^2	0.79
Water	1×10^3	1
Mercury	13.6×10^3	13.6
Glass	2.5×10^3	2.5
Aluminium	2.7×10^3	2.7
Iron	7.86×10^3	7.86
Copper	8.92×10^3	8.92
Silver	10.5×10^3	10.5
Uranium	19.07×10^3	19.07
Gold	19.3×10^3	19.3

Illustrative Examples

9. A body is found to have a mass of 500g and a volume of 47.5cm^3 . What

is

- A) Its density
- B) Its specific gravity
- C) The material

Solution :

$$A) \text{ Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{0.5}{47.5 \times 10^{-6}} = 10.5 \times 10^3 \text{ kg/m}^3$$

$$B) \text{ Relative Density} = \frac{\text{Density of body}}{\text{Density of water}} = \frac{10.5 \times 10^3}{10^3} = 10.5$$

- C) It is silver

10. What is the mass of a block of gold with dimension $10\text{cm} \times 5\text{cm} \times 4\text{cm}$?

Solution :

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}, \text{ volume} = (10)(5)(4) = 200\text{cm}^3$$

$$\text{Mass} = (\text{Density})(\text{volume}) = (19.3 \times 10^3)(200 \times 10^{-6}) = 3.86\text{kg}$$

11. If the mass of the earth is $6 \times 10^{24} \text{ kg}$ and its radius is $6.4 \times 10^6 \text{ m}$. What is its

- A) Density
- B) Relative density

Solution :

$$A) \text{ Density} = \frac{\text{Mass}}{\text{Volume}}$$

Since the earth is spherical in shape, its volume is

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}(3.14)(6.4 \times 10^6)^3 = 349.53 \times 10^{18} \text{ m}^3$$

$$\rho = \frac{M}{V} = \frac{6 \times 10^{24}}{349.5 \times 10^{18}} = 17,166 \text{ kg/m}^3$$

$$B) \text{ SG} = \frac{\rho_{\text{earth}}}{\rho_{\text{water}}} = \frac{17,166}{1000}$$

$$\text{SG} = 17.166$$

Match items in column A with those in column B

A
12. Density
13. Relative Density

- B
- a) Ratio of volume to mass
 - b) Ratio of density of water to density of substance
 - c) Ratio of density of substance to density of water
 - d) Ratio of mass to volume

Answers

12. d 13. c

8.3 Stress and Strain

The magnitude of the force that causes deformation and the amount of deformation caused on the body are described using the concepts stress and strain respectively.

Stress : Is applied force per unit area of the body

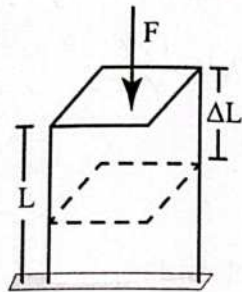
$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

Stress is a vector quantity and its SI unit is pascal, pa
 $1\text{pa} = 1\text{N/m}^2$

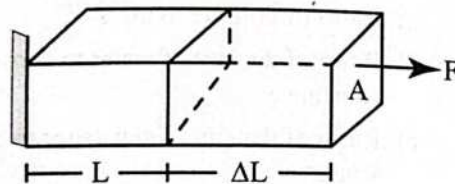
Based on the direction of the applied force on the area, stress can be tensile, compressive or shear.

For a tensile and compressive stress, the applied force is perpendicular to

the cross-sectional area of the body on which the force is exerted.

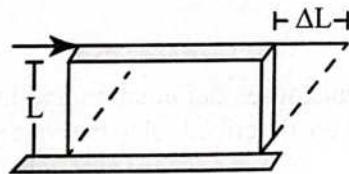


Compressive Stress



Tensile Stress

In a Shear Stress, the applied force is parallel to the cross-sectional area of the body.



Shear Stress

The deformation, that is elongation or compression of the material relative to its original size is described using the concept of *strain*.

Strain : Is the amount of deformation of a body under stress

$$\text{Strain} = \frac{\text{change in size}}{\text{original size}}$$

$$\text{Strain} = \frac{\Delta L}{L}$$

→ Strain is a unit less quantity and tells us amount of deformation.

When a body is under tensile stress, it gets tensile strain and became thinner and longer. When a body is under compressive stress, it gets compressive strain and became thicker and shorter. When a body is under shear stress, it gets shear strain and shifted side ways

8.4 Young's and Bulk Modulus

The material property that takes into account the stress and strain induced on the material is called *modulus*.

Young's Modulus : Is the ratio of the stress to the strain of a solid material

$$\text{Young's Modulus} = \frac{\text{stress}}{\text{strain}}$$

$$Y = \frac{F/A}{\Delta L/L}$$

$$Y = \frac{FL}{A\Delta L}$$

Young's modulus is expressed in pascal, $1 \text{ pa} = 1 \text{ N/m}^2$

Bulk Modulus : Is the ratio of the stress on a fluid to the strain of the gas or liquid

$$\text{Bulk Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

$$B = \frac{F/A}{\Delta V/V}$$

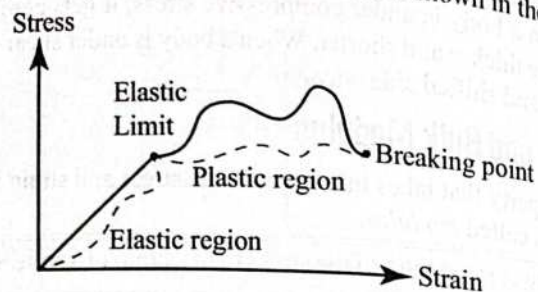
$$B = - \frac{pv}{\Delta v}$$

Strain of a fluid is the ratio of the change in volume to its initial volume.

In the above equation of bulk modulus force per area gives pressure, p and the minus sign $(-)$ tells compression.

According to Hook's law, for a ductile material, the stress is proportional to the strain until the elastic limit is reached.

The relationship between stress and strain is shown in the following graph



After the elastic limit when a force is applied on the material, the material deforms permanently.

Young's modulus of some materials is given below

Material	Young's Modulus (10^{11} pa)
Aluminium	0.70
Brass	0.91
Copper	1.10
Glass	0.72
Quartz	0.56
Steel	2.00
Tungsten	3.50

Illustrative Examples

14. How much load should be suspended on the free end of a 1m copper wire of 10mm diameter so as to stretch it 2mm?

Solution:

$$Y = \frac{FL}{A\Delta L} \Rightarrow F = \frac{YA\Delta L}{L}, \quad A = \pi r^2$$

$$F = \frac{(1.1 \times 10^{11})(3.14)(5 \times 10^{-3})^2(2 \times 10^{-3})}{1}$$

$$= 17300N$$

15. What will be the increase in length when a 200 kg load is hung on a wire

Unit - 8
of length 4m, thickness $0.2 \times 10^{-5} \text{ m}^2$ and young's modulus $0.8 \times 10^{11} \text{ pa}$?

Solution:

$$Y = \frac{FL}{A\Delta L} \Rightarrow \Delta L = \frac{FL}{AY}, \quad F = mg$$

$$\Delta L = \frac{(2000)(10)(4)}{(0.2 \times 10^{-5})(0.8 \times 10^{11})}$$

$$= 0.5 \text{ m}$$

16. What is the stress induced on a body of cross sectional area $2 \times 10^{-4} \text{ m}^2$ when a force of 1000N is applied perpendicular to it?

Solution:

$$\text{Stress} = \frac{F}{A} = \frac{1000}{2 \times 10^{-4}}$$

$$\text{Stress} = 5 \times 10^6 \text{ pa}$$

17. What is the strain of a body of length 4m if it is compressed by 2mm

Solution:

$$\text{Strain} = \frac{\Delta L}{L} = \frac{2 \times 10^{-3}}{4}$$

$$\text{Strain} = 0.5 \times 10^{-3}$$

Illustrative Examples

Match the items in column 'A' with those in column 'B'

A

18. Stress

19. Strain

20. Young's Modulus

21. Bulk Modulus

B

- Ratio of stress to strain in solid
- Ratio of stress to strain in fluid
- Ratio of force to area
- Ratio of deformation to initial size
- Ratio of strain to stress

18. C

19. d

20. a

21. b

8.5 Static Equilibrium

The word "static" means at rest and the word "Equilibrium" means in balance. Therefore, a body is in static equilibrium if it is not moving and the force and torques acting on it cancel out each other.

Static Equilibrium : Is a condition that occurs when there is no net force and no net torque acting on a body and the body is not moving.

For a body to be in static equilibrium, two conditions must be satisfied. These conditions are the first condition and the second condition of equilibrium.

8.5.1 First Condition of Equilibrium

The First condition of equilibrium also called the *translational equilibrium* prevents the body from linear motion.

The First Condition of Equilibrium states that "the sum of forces acting on the body must be zero"

That is, the sum of the forces acting on the body along the x, and y and the z axes must be zero.

$$\vec{F}_{\text{net}} = 0$$

$$\sum F_x = \sum F_y = \sum F_z = 0$$

8.5.2 Second Condition of Equilibrium

The second condition of equilibrium also known as the *rotational equilibrium* prevents the body from rotational motion.

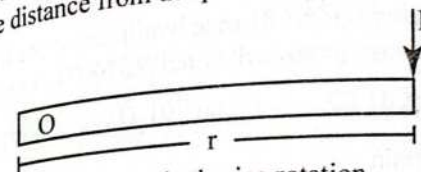
The Second Condition of Equilibrium States that; "the sum of torques acting on the body must be zero."

That is, the sum of the torques acting along the clockwise direction must be equal to the sum of torques acting along the counter clock wise direction.

$$\vec{\tau}_{\text{net}} = 0$$

$$\sum \tau \text{ clockwise} = - \sum \tau \text{ counter clockwise}$$

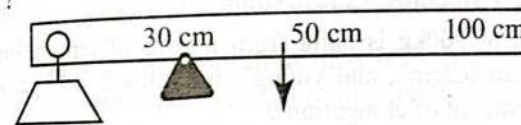
Torque, τ (tau), is the twisting or turning effect of a force and it is the product of the perpendicular components of the force and the lever arm, which is the distance from the pivot point.



$\tau = rF$, Now it is clockwise rotation

Illustrative Examples

22. If a uniform meter stick with a pivot point at the 30cm mark is balanced when a 2kg block is suspended at the 0 cm mark, what is the mass of the stick?



Solution :

Using the second condition of equilibrium

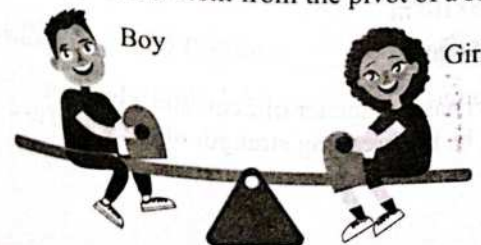
$$\tau_{\text{clockwise}} = \tau_{\text{counter clockwise}}$$

$$r_{\text{block}} M_{\text{block}} = r_{\text{stick}} M_{\text{stick}}$$

$$M_{\text{stick}} = \frac{r_{\text{block}} M_{\text{block}}}{r_{\text{stick}}} = \frac{(30)(2)}{20}$$

$$= 3\text{kg}$$

23. At what distance from the pivot should a 32kg girl sit to balance a boy of mass 26kg who sit 1.6m from the pivot of a see saw?



Solution :

$$\tau_{\text{clockwise}} = \tau_{\text{counter clockwise}}$$

$$r_{\text{boy}} M_{\text{boy}} = r_{\text{girl}} M_{\text{girl}}$$

$$r_{\text{girl}} = \frac{r_{\text{boy}} M_{\text{boy}}}{M_{\text{girl}}} = \frac{(1.6)(26)}{32}$$

$$r_{\text{girl}} = 1.3\text{m}$$

24. Young's Modulus is the

- A) Ratio of stress to strain
B) Ratio of force to area
C) Ratio of strain to stress
D) Ratio of force to deformation

Hint : Young's Modulus = stress/strain**Answer : A**

25. When a load of 500kg is hang from a wire of length 3m and cross - sectional area 0.2cm^2 , and young's modulus $2 \times 10^{11}\text{ pa}$, it stretches. What is the amount of elongation ?

- A) 3.75 mm B) 2.75 mm C) 1.75 mm D) 0.75 mm

Solution :

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}$$

$$Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L} = \frac{mgL}{A\Delta L}$$

$$\Delta L = \frac{FL}{YA} = \frac{(500)(10)(3)}{(2 \times 10^{11})(0.2 \times 10^{-4})}$$

$$\Delta L = 3.75 \times 10^{-3}\text{m}$$

$$\Delta L = 3.75\text{mm}$$

Answer : A

26. A rope made of steel has a diameter of 5cm, and a breaking strength of $2 \times 10^8\text{ N}$. What will be the breaking strength of the wire if its diameter is doubled ?

B) $4 \times 10^8\text{ N}$

C) $1 \times 10^8\text{ N}$

D) $8 \times 10^8\text{ N}$

A) $2 \times 10^8\text{ N}$

Hint : When diameter doubled, cross - sectional area quadrupled
breaking strength is proportional to cross - section area .

Answer : D

27. A wire of cross - sectional area 10^{-6} m^2 is increased in length by 0.1 % If the tension is 1000N, What is the young's modulus of the wire ?

A) 10^{12} pa

B) 10^{11} pa

C) 10^{10} pa

D) 10^9 pa

Solution :

$$Y = \frac{F/A}{\Delta L/L} = \frac{1000/10^{-6}}{0.001}$$

$$Y = \frac{1000}{10^{-9}} = 10^{12}\text{ pa}$$

Answer : A

28. A and B are two wires. The radius of A is twice that of B. They are stretched by the same load. Then, the stress on B is

A) Equal to that on A

C) Two times that on A

B) Four times that on A

D) Half that on A

$$\text{Hint : } \frac{\text{Stress on B}}{\text{Stress on A}} = \frac{F/a_B}{F/a_A} = \frac{r_A^2}{r_B^2}$$

$$\frac{\text{Stress on B}}{\text{Stress on A}} = \frac{4r_B^2}{r_B^2}$$

$$\text{Stress on B} = 4(\text{Stress on A})$$

Answer : B

29. The extension, of a wire is 3mm. What will be its extension if its radius decreases by half ?

A) 12mm

B) 0.75mm

C) 6mm

D) 15mm

Hint : Same young's modulus

$$\frac{FL}{A_1 \Delta L_1} = \frac{FL}{A_2 \Delta L_2}$$

$$A_2 \Delta L_2 = A_1 \Delta L_1$$

$$\pi r_2^2 \Delta L_2 = \pi r_1^2 \Delta L_1$$

$$\left(\frac{1}{2} r_1\right)^2 \Delta L_2 = r_1^2 (3)$$

$$\Delta L_2 = (3)(4) = 12 \text{ mm}$$

30. What force is needed to double the length of steel wire of constant cross-sectional area 1 cm^2 ($Y = 2 \times 10^{11} \text{ pa}$)

- A) $2 \times 10^{11} \text{ N}$ B) $2 \times 10^{10} \text{ N}$ C) $2 \times 10^8 \text{ N}$ D) $2 \times 10^7 \text{ N}$

Hint :

$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\Delta L/L}$$

$$F = YA = (2 \times 10^{11})(1 \times 10^{-4}) = 2 \times 10^7 \text{ N}$$

31. In an experiment, for the determination of Young's modulus of a wire, when the length and the applied force are doubled, the Young's modulus will?

- A) Remain constant C) Become four times
B) Become doubled D) Become sixteen times

Hint : Young's modulus is material property.

32. Copper wire and a steel wire of the same diameter and length are connected end to end and a force caused their combined length to stretch by 1 cm . Then, the two wires will have

- A) Same stress and strain B) Same stress, different strain
C) Same strain, different stress D) Different stress and strain

Hint : Different deformation level.

33. The Young's modulus of a wire of length L and radius R is Y . What will

be the young's modulus of the wire if its length is doubled and its radius is halved ?

B) Y

C) $0.5 Y$

D) $8 Y$

A) $2 Y$

Hint : Young's modulus do not depend on material geometry

Answer : B

34. A wire is stretched by 1 mm , what will be its stretch if the applied force is doubled and the radius is halved ?

A) 8 mm

B) 4 mm

C) 2 mm

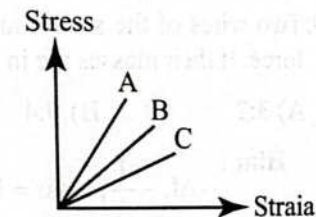
D) 1 mm

$$\text{Hint : Strain} = \frac{\Delta \ell}{\ell}$$

Answer : A

35. The stress - strain graph for brass, steel and rubber are given. The lines A, B and C are respectively for

- A) Steel, brass and rubber
B) Brass, steel and rubber
C) Steel, rubber and brass
D) Rubber, steel and brass



Hint : Compare the strain for the same stress

Answer : A

36. Two wires of the same radius and material have lengths in the ratio $1:2$. what will be the ratio of their strains when subjected to the same force ?

A) $1:1$

B) $1:2$

C) $2:1$

D) $1:4$

$$\text{Hint : Strain} = \frac{\Delta \ell}{\ell}$$

Answer : A

37. What force is needed to stretch a 2 m wire of cross-sectional area 2 mm^2 by 0.5 mm ($Y = 2.2 \times 10^{11} \text{ pa}$)

A) $1.1 \times 10^5 \text{ N}$

B) $1.1 \times 10^4 \text{ N}$

C) $1.1 \times 10^3 \text{ N}$

D) $1.1 \times 10^2 \text{ N}$

Solution :

$$Y = \frac{FL}{A\Delta L} \Rightarrow F = \frac{YA\Delta L}{L}$$

$$F = \frac{(2.2 \times 10^{11})(2 \times 10^{-6})(0.5 \times 10^{-3})}{2}$$

$$= 1.1 \times 10^2 \text{ N}$$

38. A Cable is replaced by another one of the same length and material but of twice the diameter. The elongation would now become ;

A) Double

B) One - half

C) One - fourth

D) One - sixth

Hint : $Y = \frac{FL}{A\Delta L} \Rightarrow \Delta L \sim \frac{1}{A}$

$$\Delta L \sim \frac{1}{d^2}$$

39. Two wires of the same material and length are stretched by the same force. If their masses are in the ratio 3:2 Their deformations are in ratio;

A) 3:2

B) 9:4

C) 2:3

D) 4:9

Hint :

$$\Delta L \sim \frac{1}{A}, \text{ mass} = LA\rho$$

$$\Delta L \sim \frac{1}{m} \Rightarrow \frac{\Delta L_1}{\Delta L_2} = \frac{m_2}{m_1} = \frac{2}{3}$$

40. If the stress applied on a wire is equal in magnitude to the Young's modulus. The deformation of the wire will be equal to ;

A) Its original length

C) Twice its length

B) Half of its length

D) Four times its length

Hint : $Y = \frac{F\Delta L}{AL} = \frac{\text{stress}}{\Delta L/L} = \frac{\Delta L}{L} = 1$

$$\Delta L = L$$

41. The dimensions of four wires of the same material and stress are given

below. Which wire will have maximum deformation ?

A) Length 100cm, Diameter 1mm

B) Length 200cm, Diameter 2mm

C) Length 300cm, Diameter 3mm

D) Length 50cm, Diameter 0.5mm

Hint : $Y = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$

$$\Delta L = \frac{FL}{AY} = \frac{\Delta FL}{\pi d^2 Y} = \Delta L \sim \frac{L}{d^2}$$

$$\frac{100}{(1)^2} = 100, \frac{200}{(2)^2} = 50, \frac{300}{(3)^2} = 33.33, \frac{50}{(0.5)^2} = 200$$

Answer : D

End of unit Questions and problems

I. Give Short Answers to the Following Questions

1. What is Elasticity ?

2. What is Plasticity ?

3. What is Stress ?

4. What is Strain ?

5. What is Elastic Limit ?

6. What is Youngster's modulus ?

7. What is Bulk modulus

8. State Hooke's Law

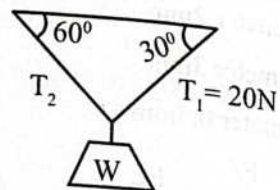
9. What is Static Equilibrium ?

10. Explain the two conditions of equilibrium

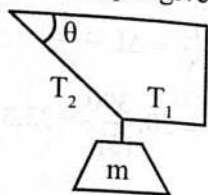
11. What is Torque ?

II. Solve the following problems

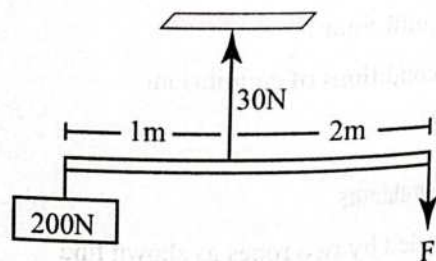
12. A block is suspended by two ropes as shown find

A) Tension, T_2 B) Weight, W 

13. What are the tensions in the two ropes given that $\theta = 30^\circ$ and $m = 200 \text{ kg}$

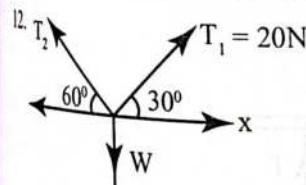


14. What force is required to double the length of a steel wire of cross-sectional area 0.1 cm^2
15. A uniform beam of 1 m length is supported by a cable of tension force 500 N at a distance of 20 cm from one end. What is the weight of the beam?
16. A wire of young's modulus $13.78 \times 10^{10} \text{ N/m}^2$, length 4 m and diameter 4 mm is stretched when a 4 kg mass is suspended on it. What is its deformation?
17. Two wires A and B are made of the same material. If wire A has twice the length and twice the diameter of wire B. What will be the ratio of their deformations when subjected to the same load?
18. What should be the value of F so that the system will be in equilibrium?



- Elasticity is the property of a body by virtue of which it regains its original size and shape when the deforming force is removed.
- Plasticity is the opposite of elasticity.
- Stress is force per unit area.
- Strain is deformation per original size.
- Elastic limit is the maximum stress level beyond which the body deforms permanently.
- Young's modulus is the ratio of stress to strain.
- Bulk modulus is the ratio of stress to volume strain.
- Hooke's law states that; stress is proportional to strain until the elastic limit.
- Static equilibrium is a condition for which the sum of forces and torques acting on a body are zero
- First condition, which states that all forces acting on a body add up to zero. And second condition states that clockwise torque acting on a body is equal to the counter clockwise torque acting on the body;
- Torque is the turning or twisting effect of a force acting on a body.

Solution to End of unit problems



$$A) \sum F_x = 0$$

$$T_1 \cos 30^\circ - T_2 \cos 60^\circ = 0$$

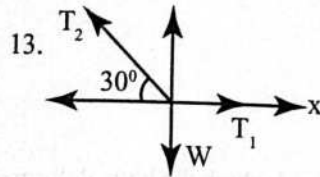
$$(20)(0.867) = T_2 (0.5)$$

$$T_2 = 34.6 \text{ N}$$

$$B) \sum F_y = 0$$

$$T_1 \sin 30^\circ + T_2 \sin 60^\circ = W$$

$$W = 20(0.5) + 34.6(0.867) = 40\text{N}$$



$$\sum F_x = 0$$

$$T_1 - T_2 \cos 30^\circ = 0$$

$$T_1 = 0.867 T_2 \dots \dots \dots (*)$$

$$\sum F_y = 0$$

$$T_2 \sin 30^\circ - W = 0$$

$$T_2(0.5) = mg = (200)(10) = 4000\text{N}$$

Substitute for T_2 into equation(*)

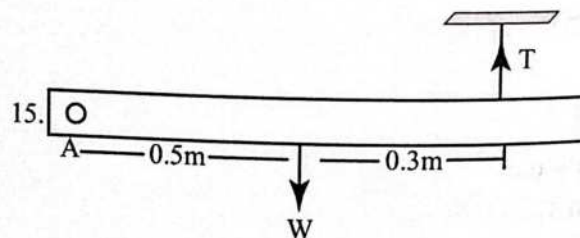
$$T_1 = 0.867(4000) = 3468\text{N}$$

$$14. Y = \frac{F_1 L}{A \Delta L_1} \Rightarrow F_1 = \frac{Y A \Delta L_1}{L}$$

$$F_2 = \frac{Y A \Delta L_2}{L} = \Delta L_2 = L$$

$$F_2 = Y A = (2 \times 10^{11})(0.1 \times 10^{-4})$$

$$F_2 = 2 \times 10^6 \text{ N}$$



Let point A be pivot point

$$0.5 W = 0.8 T$$

$$W = 1.6 T = 1.6 (500) = 800\text{N}$$

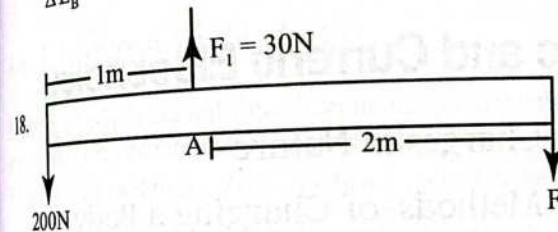
$$16. Y = \frac{FL}{A \Delta L} = \Delta L \Rightarrow \frac{FL}{AY}, F = mg$$

$$\Delta L = \frac{mgL}{AY} = \frac{4(10)(4)}{\pi (2 \times 10^{-3})^2 (13.78 \times 10^{10})}$$

$$\Delta L = 0.09 \times 10^{-3} \text{ m} = 0.09 \text{ mm}$$

$$17. Y = \frac{FL_A}{\pi r_A^2 \Delta L_A} \text{ and } Y = \frac{FL_B}{\pi r_B^2 \Delta L_B}$$

$$\frac{\Delta L_A}{\Delta L_B} = \frac{1}{2}$$



Let A be pivot point

$$F_2(2) = 200(1) \Rightarrow F_2 = F = 100\text{N}$$

UNIT 9

9 . Static and Current Electricity

- 9.1 Charges in Nature
- 9.2 Methods of Charging a Body
- 9.3 The Electroscope
- 9.4 Electrical Discharge
- 9.5 Coulomb's Law
- 9.6 Electric Field
- 9.7 Electric Circuits
- 9.8 Current, Voltage and Ohm's Law

9. Static and Current Electricity

You are welcome to this incredible unit where you will be able to know charges in nature, describe methods of charging, explain the working principle of electroscope, state coulomb's law, examine the nature of current, voltage and resistance in series and parallel combinations. Know how to use Ammeter and Voltmeter in an electric circuit and understand the electrical safety rules. Enjoy the lesson!

9.1 Charges in Nature

In nature, a body is neutral since it, contains equal number of electrons and protons carrying negative and positive charges respectively.

A body is then said to be *charged* when it gained or lost electrons.

A body is said to be negatively charged when it gained electrons and positively charged when it lost electrons.

Charge is a scalar quantity and Its SI unit is the coulomb(C).

From the principle of quantization of charge, the smallest charge that exists so far is the charge carried by an electron or proton and its magnitude is;

$$e = 1.6 \times 10^{-19} \text{ C}$$

The amount of charge a body possessed is then obtained by the relation.

$$Q = ne$$

Where: Q = Charge carried by the body.

n = number of electrons gained or lost.

e = charge of an electron, = $1.6 \times 10^{-19} \text{ C}$

Just like the mass, energy and momentum of an isolated system, charge is also conserved.

For an isolated system, charge is neither created nor destroyed but transferred from one body to the other.

- ✓ An isolated system is a system that does not interact with the surrounding. Any form of exchange like energy and charge is within itself.

Illustrative Example

1. What is an electrically neutral body?

Explanation:

A neutral body is a body with equal number of electrons and protons.

2. What are the types of charges exist in nature?

Explanation:

Negative charge carried by electrons and positive charge carried by protons.

3. When do we say that a body is positively charged?

Explanation:

When it lost electrons.

4. State the law of conservation of charge

Explanation:

Charge is neither created nor destroyed it only transferred from one body to other.

5. What does it mean when we say charge is quantized

Explanation:

It means, charge exists in a discrete amount as an integer multiple of the charge of an electron.

6. State the fundamental law of electrostatics

Explanation:

Like charge repel each other and unlike charges attract each other.

7. What is electrostatics or static electricity?

Explanation

It is the study of charges at rest.

8. How many electrons are there in one coulomb of charge?

Solution:

$$Q = ne$$

$$n = \frac{Q}{e} = \frac{1}{1.6 \times 10^{-19}}$$

$$= 6.25 \times 10^{18} \text{ electrons}$$

9. How many charges are carried by a body that lost 1000 electrons

Solution:

$$Q = ne$$

$$Q = (1000)(1.6 \times 10^{-19})$$

$$= 1.6 \times 10^{-16} \text{ C}$$

10. Body A carrying a 500C charge is made in contact with body B carrying -1500C charge, after contact, what will be;

- A. Charge carried by each body
B. Number of electrons lost or gained by each body.

Solution

$$a. Q = \frac{Q_A + Q_B}{2} = \frac{(500) + (-1500)}{2}$$

$$= -500 \text{ C}$$

$$b. Q = ne \Rightarrow n = \frac{Q}{e} = \frac{500}{1.6 \times 10^{-19}}$$

$$= 3.125 \times 10^{17} \text{ electrons}$$

Keep in mind that; For charges at rest:
Charges of the same sign repel each other and charges of opposite

sign attract each other

- ✓ Total charge of an isolated system is conserved.
- ✓ Charge is quantized and hence, net charge on a body is determined as the integer multiple of the basic charge. $e = 1.6 \times 10^{-19} \text{C}$

$$Q = ne$$

n = number of electrons gained or lost by the body

$e = 1.6 \times 10^{-19} \text{C}$, charge carried by a proton or an electron.

- ✓ The electric field lines are radially outward from a positive charge and radially inward towards a negative charge.

9.2 Methods of Charging a Body

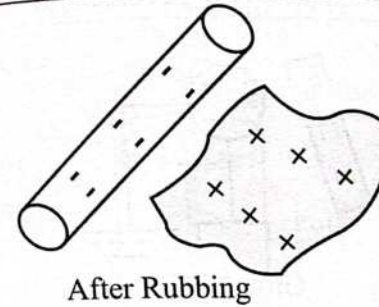
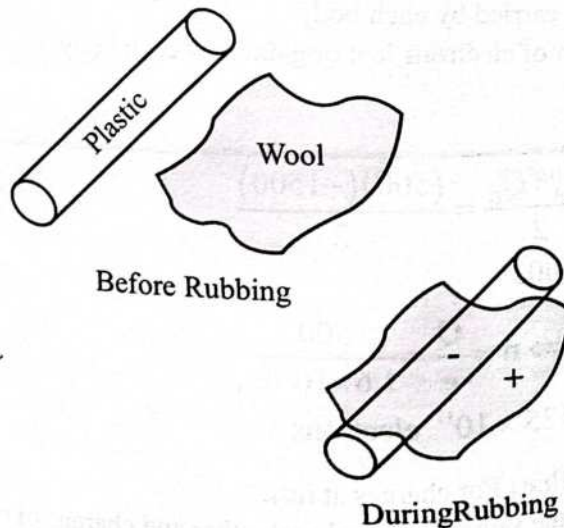
The process of adding or removing electrons from a body is called *charging* or *electrifying*.

The well known mechanisms of charging a body are rubbing, conduction and induction.

Charging by Rubbing

It involves the transfer of electrons from one body to the other when two *neutral* bodies are rubbed together.

For example, when a neutral plastic rod and a neutral wool cloth are rubbed together, they become charged.



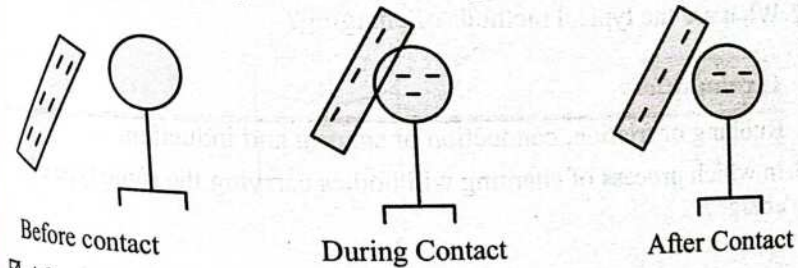
After Rubbing

- ✓ After the process of charging by rubbing the two bodies become *oppositely* charged

Charging by Conduction

It involves the sharing of charges between a *charged* body and a *neutral* body when they are made in contact.

For example, when a negatively charged rubber rod is made in contact with a metal sphere, the sphere becomes charged.

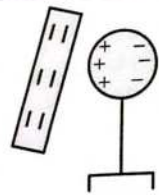


- ✓ After the process of charging by conduction, the two bodies carry charges of the *same sign*.

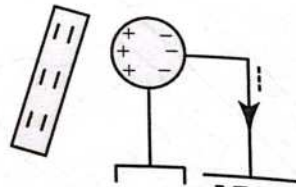
Charging by Induction

It involves the formation of electric polarities when a charged body is brought closer to a neutral body.

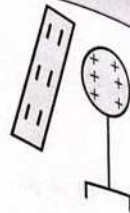
For example, when a negatively charged glass rod is brought very close but not in physical contact to a neutral metal sphere, electric poles are formed on the sphere.



Polarization



Grounding



After Induction

- ✓ After the process of charging by induction, the two bodies become oppositely charged.

Illustrative Example

11. What is charging?

Explanation:

It is the process of adding to or removing from a body electrons.

12. What are the typical methods of charging?

Explanation:

Rubbing or friction, conduction or sharing and induction.

13. In which process of charging will bodies carrying the same type of charge?

Explanation:

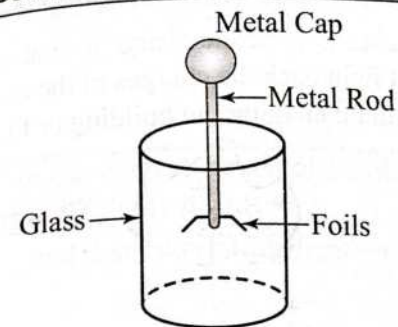
Charging by conduction gives rise to same type of charge. However, charging by rubbing and induction left the bodies oppositely charged.

9.3 The Electroscope

To know whether a body is electrically charged or not we use a device called an *electroscope*.

Electroscope: Is a device that is used to detect the presence of an electric charge on a body.

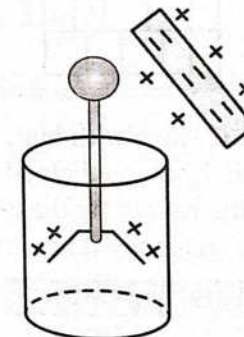
A typical electroscope consists of a metal cap, a metal rod, foils of gold or aluminium in a glass jar as shown.



Typical Electroscope

The collapsing or diverging of the leaves of the foils indicates the presence of charge on body.

When a positively charged rod is brought closer without touching the metal cap, positive charge is induced in the foils and they diverge.



Foils Diverge

Typical Electroscope

9.4 Electrical Discharge

A charged body can be made neutral by the process of *discharging*.

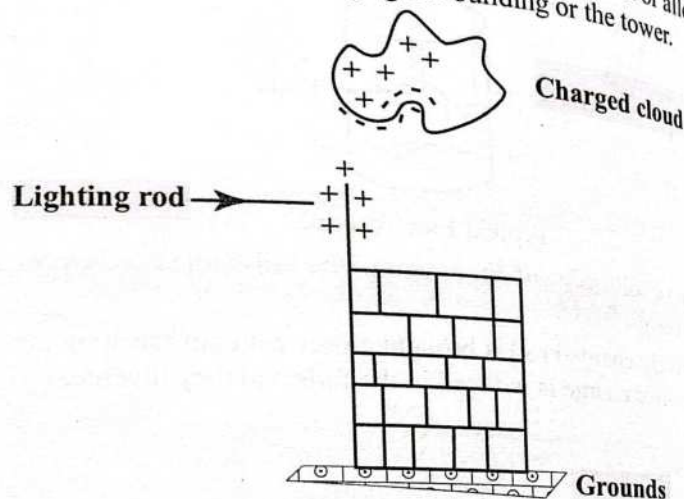
Discharging: Is the process of removing charges from a charged body.

The production of sparks is an example of discharging a charged body.

The Lightning Rod

The rod that prevents buildings and towers from the damage of lightning is known as a lightning rod. The working principle of a lightning rod is that, when

a charged cloud approaches it, opposite charge to that of the cloud will be induced on its tips and it fight back the charges of the cloud or allow a path way to the ground with out damaging the building or the tower.



- ☑ Lighting is an electromagnetic wave with huge amount of heat caused by the discharging of oppositely charged cloud layer followed by a thunder storm of terrific sound caused by the difference in pressure of air column. If lightning falls on a body it may trigger a huge damage.

Illustrative Examples

14. What is an electroscope?

Explanation:

It is a device that is used to, detect charge on a body and identify the type of charge carried by the body.

15. What is discharging?

Explanation:

It is the process of removing charge from a charged body.

16. How is lighting formed?

Explanation:

It is formed when two oppositely charged cloud layers made contact

17. What is lighting rod?

Explanation:

It is a metal rod that is fixed at the top of a building or a tower so as to keep it safe from the lighting damage.

18. What are the dos and don't dos during lighting ?

Explanation:

Things advised during heavy rain are; get shelter inside a house or a car, and avoid yourself from sources of electromagnetic wave such as phone, and don't stand under a tree, don't expose yourself to a place where there is a potential of lighting strike.

9.5 Coulomb's Law

The magnitude of the force of attraction or repulsion between two point charges was discovered by Charles Coulomb

Coulomb's Law: States that ; the magnitude of the electrostatic force between two point charges is directly proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance between the charges.

That is, if we have two charges Q_1 and Q_2 a distance r apart,

$$Q_1 \text{ ————— } r \text{ ————— } Q_2$$

Then, $F \sim Q_1 Q_2$ and

$$F \sim \frac{1}{r^2}$$

$$\Rightarrow F \sim \frac{Q_1 Q_2}{r^2},$$

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

$$k = \frac{1}{4\pi\epsilon_0}$$

$$F = \frac{kQ_1Q_2}{r^2}$$

Where: $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$ and is called *permittivity of free space*
 $K = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$ and is called the *electrostatic constant*.

Illustrative Examples

19. What is the magnitude and nature of the electrostatic force between two point charges, $Q_1 = 2 \times 10^{-6} \text{ C}$ and $Q_2 = -4 \times 10^{-3} \text{ C}$ that are 3cm apart?

Solution:

$$F = \frac{kQ_1Q_2}{r^2} = \frac{(9 \times 10^9)(2 \times 10^{-6})(4 \times 10^{-3})}{(3 \times 10^{-2})^2}$$

$$F = 8 \times 10^4 \text{ N, attractive}$$

20. If the electrostatic force between two point charges is 400N. What will be the force between these point charges if their separation is

- A. Doubled
 B. Halved

Solution:

$$F_1 = \frac{kQ_1Q_2}{r_1^2} = 400 \text{ N}$$

$$\text{A. } F_2 = \frac{kQ_1Q_2}{r_2^2}, r_2 = 2r_1$$

$$F_2 = \frac{kQ_1Q_2}{(2r_1)^2} = \frac{1}{4} \frac{kQ_1Q_2}{r_1^2}$$

$$= \frac{1}{4}(F_1) = \frac{400}{4} = 100 \text{ N}$$

$$\text{B. } F = \frac{kQ_1Q_2}{r_1^2} = 400 \text{ N}$$

$$F_2 = \frac{kQ_1Q_2}{(2r_2)^2}, r_2 = \frac{1}{2}r_1$$

$$F_2 = \frac{kQ_1Q_2}{\left(\frac{1}{2}r_1\right)^2} = 4 \frac{kQ_1Q_2}{r_1^2}$$

$$4(F_1) = (400)4 = 1600 \text{ N}$$

21. What is the separation between an electron and a proton if the force of attraction between them is 0.01N

Solution:

$$F = \frac{kQ_1Q_2}{r^2} = \frac{(9 \times 10^9)(1.6 \times 10^{-19})(1.6 \times 10^{-19})}{r^2} = 0.01$$

$$r^2 = 23.04 \times 10^{-27}$$

$$r = 4.5 \times 10^{-13} \text{ m}$$

22. What is the repulsive force between two electrons that are 3mm apart?

Solution:

$$F = \frac{kQ_1Q_2}{r^2} = \frac{(9 \times 10^9)(1.6 \times 10^{-19})(1.6 \times 10^{-19})}{(3 \times 10^{-3})^2}$$

$$F = 2.56 \times 10^{-23} \text{ N}$$

23. The electrostatic force between two point charges of 100C and -200C is 50N. What will be the force between these charges if they are made to contact and then placed at their initial position?

Solution:

$$F_1 = \frac{kQ_1Q_2}{r^2} = \frac{(9 \times 10^9)(100)(200)}{r^2} = 50\text{N}$$

And, after contact, the charges are going to be

$$Q_1 = Q_2 = \frac{Q_1 + Q_2}{2} = \frac{(100) + (-200)}{2} = -50\text{C}$$

$$F_2 = \frac{kQ_1Q_2}{r^2} = \frac{(9 \times 10^9)(50)(50)}{r^2}$$

$$F_2 = \frac{(9 \times 10^9)(2500)}{(9 \times 10^9)(20000)}, \quad r^2 = \frac{(9 \times 10^9)(20000)}{50}$$

$$F_2 = 6.25\text{N}$$

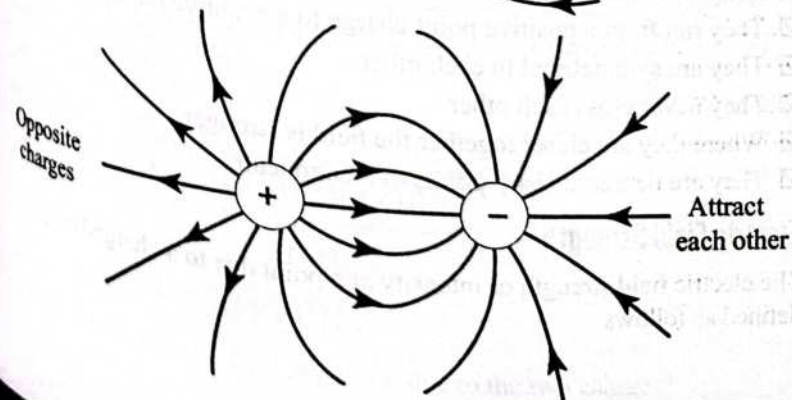
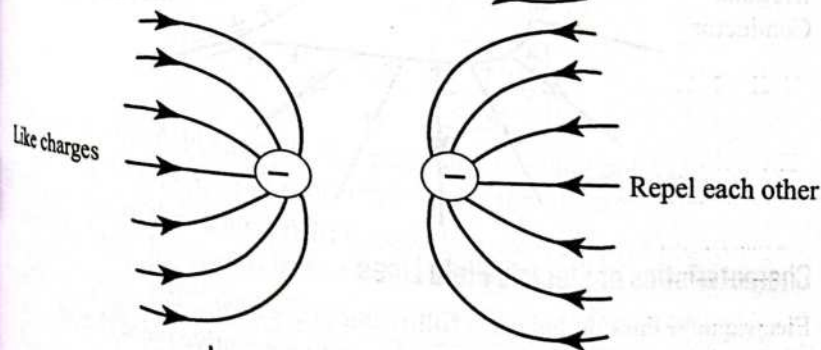
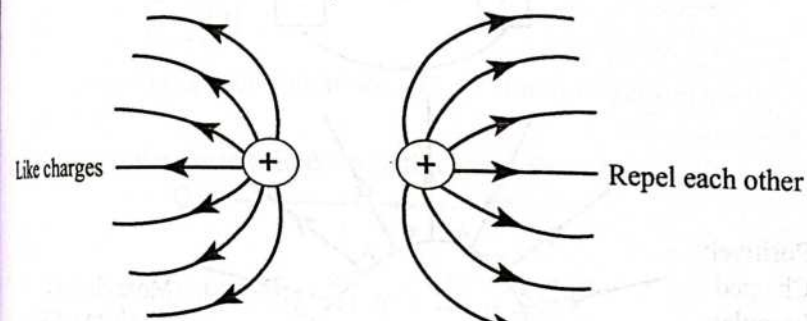
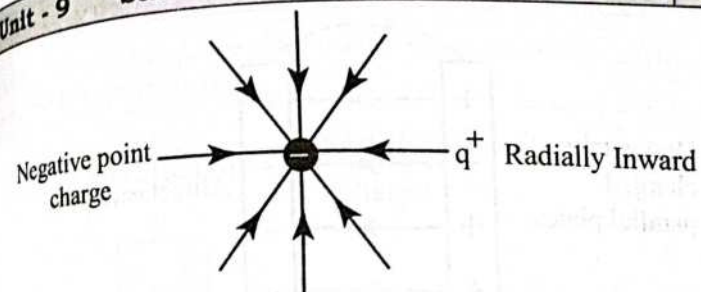
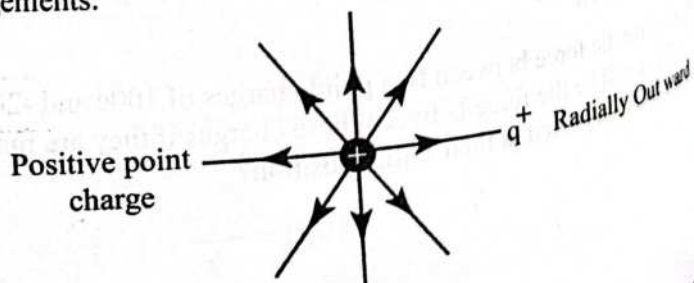
9.6 Electric Field

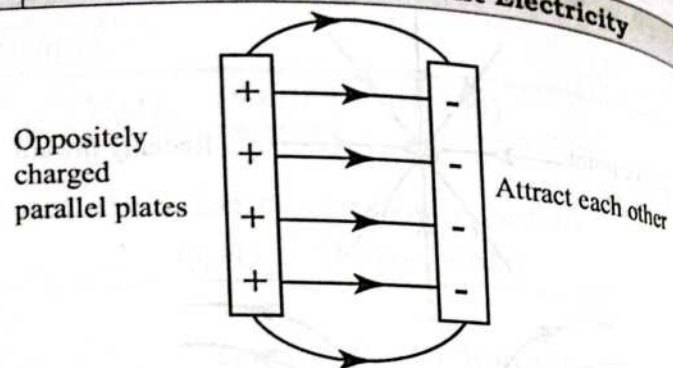
The field where an electric force is felt by a charged particle is called an *electric field*.

Electric Field: Is the region around a charged body where a test charge experiences an electrostatic force.

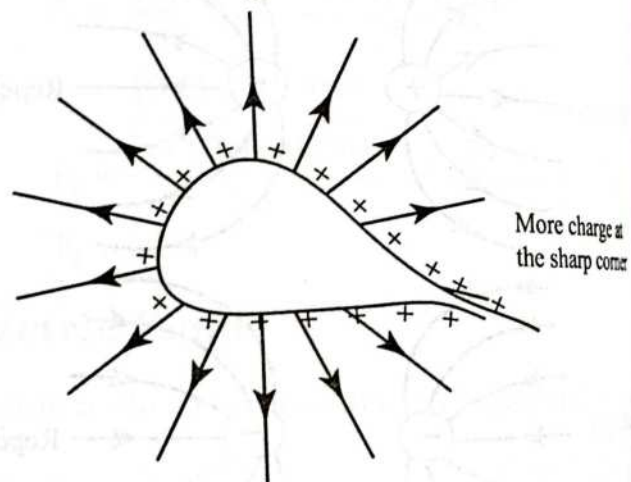
To visualize the electric field of a point charge, we use imaginary lines called *electric field lines*. And, to detect the presence of a point charge, we use a small positive charge called a *test charge*, q^+

Now, let us examine the nature of the field lines for different charge arrangements.





Positively
Charged
Irregular
Conductor



Characteristics of Electric Field Lines

Electric field lines do have the following properties

- ☑ They run from a positive point charge to a negative point charge.
- ☑ They are symmetrical to each other
- ☑ They never cross each other
- ☑ Where they are closer together the field is stronger
- ☑ They are denser at sharp points of a conductor

Electric Field Strength

The electric field strength or intensity at a point due to a charged body defined as follows

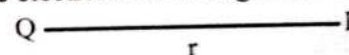
Electric Field Strength: Is the electrostatic force per unit positive charge exerted on a test charge.

$$\text{Electric Field Strength} = \frac{\text{Electric Force}}{\text{Charge}}$$

$$\vec{E} = \frac{\vec{F}}{Q}$$

Electric field strength is a vector quantity and its SI unit is Newton per Coulomb, (N/C)

For a point charge, the electric field strength can be obtained as follows



At point P, the electric field strength is $E = \frac{F}{Q^+} = \frac{kQQ^+}{r^2 / Q^+}$

$$E = \frac{kQ}{r^2}$$

And, the net electric field strength at a point due to many point charges is obtained using the super-position principle of vector addition

- ☑ The direction of the electric field is radially outward from a positive charge and radially inward from a negative charge.

Illustrative Example

24. What is the electric field strength of a $3\mu\text{C}$ point charge at distance of 6cm

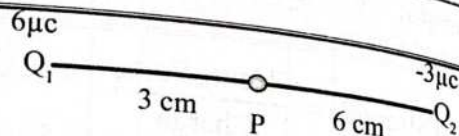
Solution:

$$E = \frac{kQ}{r^2} = \frac{(9 \times 10^9)(3 \times 10^{-6})}{(6 \times 10^{-2})^2}$$

$$E = 7.5 \times 10^6 \text{ N/C}$$

25. What is the net electric field at point P due to the two charges?

Solution:



At point P, we assume a test charge and the nature of the electric field at that point is as shown below,

$$\longrightarrow E_1$$

$$\longrightarrow E_2$$

$$E_P = E_1 + E_2$$

$$E_P = \frac{kQ_1}{r_1^2} + \frac{kQ_2}{r_2^2}$$

$$E_P = \frac{(9 \times 10^9)(6 \times 10^{-6})}{(3 \times 10^{-2})^2} + \frac{(9 \times 10^9)(3 \times 10^{-6})}{(6 \times 10^{-2})^2}$$

$$E_P = 6.75 \times 10^7 \text{ N/C}$$

26. What is the electric force exerted on a $3.5 \mu\text{C}$ charge by charge by a 250 N/C electric field directed due east?

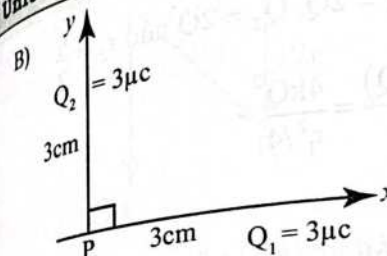
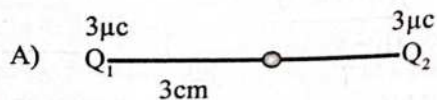
Solution:

$$E = \frac{F}{Q} \Rightarrow F = EQ$$

$$F = (250)(3.5 \times 10^{-6})$$

$$F = 8.75 \times 10^{-4} \text{ N}$$

27. What is the net electric field strength at point P



Solution:

$$A. E_P = E_1 - E_2 = \frac{kQ_1}{r_1^2} - \frac{kQ_2}{r_2^2}$$

$$E_P = 9 \times 10^9 \left[\frac{3 \times 10^{-6}}{(3 \times 10^{-2})^2} - \frac{3 \times 10^{-6}}{(3 \times 10^{-2})^2} \right] = 0$$

$$E_P = \sqrt{E_1^2 + E_2^2} = \sqrt{\left(\frac{kQ_1}{r_1^2} \right)^2 + \left(\frac{kQ_2}{r_2^2} \right)^2}$$

$$B. E_P = \sqrt{\frac{9 \times 10^9 (3 \times 10^{-6})}{(3 \times 10^{-2})^2} + \frac{9 \times 10^9 (3 \times 10^{-6})}{(3 \times 10^{-2})^2}} = 7.5 \times 10^3 \text{ N/C}$$

28. If the electrostatic force between two identical point charges is F , then what will be the force between them if their charges are doubled and their separation is halved?

A. $16F$

B. $8F$

C. $4F$

D. $2F$

Solution:

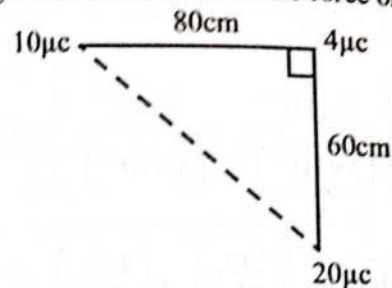
$$F_1 = \frac{kQ_1Q_2}{r_1^2} = \frac{kQ^2}{r_1^2} = F$$

$$F_2 = \frac{kQ_1Q_2}{r_2^2}, Q_1 = 2Q, Q_2 = 2Q \text{ and } r_2 = \frac{r_1}{2}$$

$$F_2 = \frac{k(2Q)(2Q)}{\left(\frac{r_1}{2}\right)^2} = \frac{4kQ^2}{r_1^2/4}$$

$$F_2 = \frac{16kQ^2}{r_1^2} = 16F$$

29. What is the magnitude of the electrostatic force on the $20\mu\text{C}$ charge? Answer: A



- A. 5N B. 4N C. 3.4N D. 2.4N

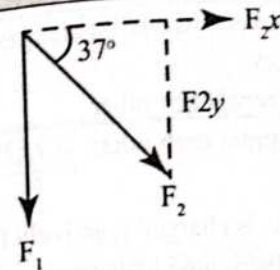
Solution:

Force between the $4\mu\text{C}$ and $20\mu\text{C}$ is,

$$F_1 = \frac{kQ_1Q_2}{r_1^2} = \frac{(9 \times 10^9)(4 \times 10^{-6})(20 \times 10^{-6})}{(60 \times 10^{-2})^2} = 2\text{N}$$

And, the force between the $10\mu\text{C}$ and $20\mu\text{C}$ is,

$$F_2 = \frac{kQ_2Q_2}{r_2^2} = \frac{(9 \times 10^9)(10 \times 10^{-6})(20 \times 10^{-6})}{(100 \times 10^{-2})^2} = 1.8\text{N}$$



$$F_x = F_{1x} + F_{2x} = 0 + (1.8)\cos 37^\circ = (1.8)(0.8) = 1.44\text{N}$$

$$F_y = F_{1y} + F_{2y} = 2 + (1.8)\sin 37^\circ = 2 + (1.8)(0.6) = 3.08$$

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{(1.44)^2 + (3.08)^2}$$

$$F = 3.4\text{N}$$

Answer: C

30. A spherical conductor of radius 5cm carries a charge of $10\mu\text{C}$. What are the electric field strength at 1cm, 5cm and 10cm from the centre of the sphere respectively in N/c?

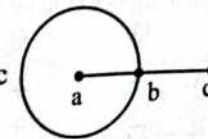
- A. $36 \times 10^8, 9 \times 10^8, 0$ C. $0.9 \times 10^8, 36 \times 10^6$
B. $9 \times 10^6, 36 \times 10^6, 0$ D. $0.36 \times 10^6, 9 \times 10^6$

Solution:

$$E_a = \frac{kQ}{r_a^2} = 0$$

$$E_b = \frac{kQ}{r_b^2} = \frac{(9 \times 10^9)(10 \times 10^{-6})}{(5 \times 10^{-2})^2} = 36 \times 10^6 \text{ N/c}$$

$$E_c = \frac{kQ}{r_c^2} = \frac{(9 \times 10^9)(10 \times 10^{-6})}{(10 \times 10^{-2})^2} = 9 \times 10^6 \text{ N/c}$$



Answer: D

31. Which one of the following statement is in disagreement with coulomb's law

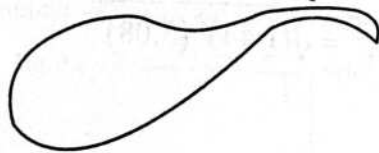
- A. The electrostatic force between two point charges is directly proportional to the square of the distance between them

- B. The electrostatic force between two point charges is proportional to the product of their charges
C. Bodies of the like charge repel each other
D. Bodies of unlike charge attract each other

Hint: $F = kQ_1Q_2/r^2$

2. If the conductor shown below is charged positively then;

- A. The charge is uniformly distributed inside
B. The charge is uniformly distributed outside
C. The electric field is maximum inside
D. The charge density is maximum at the tip



Hint: The charge distributed outside and its density is maximum at the sharp edge.

3. If a positively charged plastic rod charged a neutral metal sphere by conduction, the sphere will be charged

- A. Positively
B. Negatively
C. Positively and Negatively
D. Neutral

Hint: Conduction given rise to similar charged bodies

4. If charge Q_1 attracts charge Q_2 and charge Q_2 repels charge Q_3 , Then, their signs would be?

	Q_1	Q_2	Q_3
A.	+	+	+
B.	-	+	+
C.	+	-	+
D.	-	+	-

Hint: Use the fundamental law of electrostatics

35. The electrostatics force between two point charge is $4 \times 10^{-3} \text{ N}$ when they are 3m apart. For what separation will the force between them become $1.6 \times 10^{-2} \text{ N}$?

Answer: A

Answer: D

Answer: B

- A. 2.5m
B. 1.5m
C. 2m
D. 4m

Solution:

$$F_1 = \frac{kQ_1Q_2}{r_1^2}$$

$$4 \times 10^{-3} = \frac{kQ_1Q_2}{(3)^2} \Rightarrow kQ_1Q_2 = (4 \times 10^{-3})(9)$$

$$1.6 \times 10^{-2} = \frac{(4 \times 10^{-3})(9)}{r_2^2}$$

$$r_2^2 = \frac{36 \times 10^{-3}}{1.6 \times 10^{-2}} = 2.25$$

$$r_2 = 1.5 \text{ m}$$

Answer: B

36. A particle of mass $1.5 \times 10^{-4} \text{ kg}$ is released at a place where there is an electric field of $2.4 \times 10^4 \text{ N/C}$. If the particle experiences an acceleration of $4 \times 10^2 \text{ m/s}^2$, then what is the charge carried by the particle?

- A. $4 \mu\text{C}$
B. $3 \mu\text{C}$
C. $2.5 \mu\text{C}$
D. $2 \mu\text{C}$

Solution:

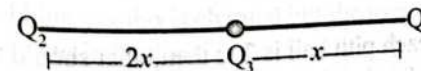
$$EQ = ma$$

$$Q = \frac{ma}{E} = \frac{(1.5 \times 10^{-4})(4 \times 10^2)}{2.4 \times 10^4} = 2.5 \times 10^{-6} \text{ C}$$

$$Q = 2.5 \mu\text{C}$$

Answer: C

37. For the net force on Q_3 to be zero, the relation between Q_1 and Q_2 must be



- A. $Q_2 = -4Q_1$
B. $Q_2 = 4Q_1$
C. $Q_2 = 2Q_1$
D. $Q_2 = -2Q_1$

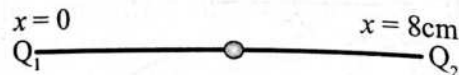
Solution:

$$\frac{kQ_1Q_3}{x^2} = \frac{kQ_2Q_3}{(2x)^2}$$

$$\frac{Q_1}{x^2} = \frac{Q_2}{4x^2}$$

$$Q_2 = 4Q_1$$

38. What is the relationship between Q_1 and Q_2 if their resultant electric field is zero at $x = 16\text{cm}$



A. $Q_1 = 4Q_2$

B. $Q_1 = 2Q_2$

C. $Q_2 = 0.24Q_1$

D. $Q_1 = -0.25Q_2$

Solution:

$$\frac{kQ_1}{r_1^2} = \frac{kQ_2}{r_2^2}, r_1 = 2r_2$$

$$\frac{Q_1}{(2r_2)^2} = \frac{Q_2}{r_2^2}$$

$$\frac{Q_1}{4} = Q_2$$

$$Q_1 = 4Q_2$$

Answer: A

39. The electric field strength at a point is defined by the force exerted on:

A. A point charge

B. A test charge

C. An electron

D. A proton

Answer: B

40. If the charge on each pith ball is 2nc then, what should the distance between them be for the electrostatic force to balance the weight of the upper ball?

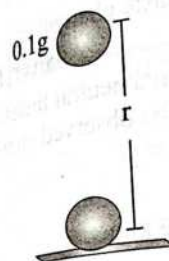
A. 6cm

B. 6mm

C. 1,8cm

D. 1.8mm

Solution:



$$\frac{kQ_1Q_2}{r^2} = \frac{kQ^2}{r^2} = mg$$

$$r = Q\sqrt{\frac{k}{mg}} = (2 \times 10^{-9}) \sqrt{\frac{9 \times 10^9}{(0.1 \times 10^{-3})(10)}}$$

$$r = 6 \times 10^{-3}\text{m} = 6\text{mm}$$

Answer: B

41. Two point charges repel each other with a force of 0.16N when their separation is 1.5m. What will be the electrostatic force between them if their separation is 1m?

A. 0.36N

B. 0.64N

C. 0.54N

D. 0.24N

Solution:

$$F_1 = \frac{kQ_1Q_2}{r_1^2}$$

$$0.16 = \frac{kQ_1Q_2}{(1.5)^2} \Rightarrow kQ_1Q_2 = (0.16)(1.5)^2$$

$$F_2 = \frac{kQ_1Q_2}{r_2^2} = \frac{(0.16)(1.5)^2}{(1)^2} = 0.36\text{N}$$

Answer: A

42. A girl observed that a comb rubbed through her hair attracted piece of papers. What is the cause of this phenomena?

A. Rubbing

B. Induction

C. Conduction

D. Radiation

Hint: The rubbing combo is charged but the papers are neutral and the attraction is due to induction.

Answer: B

43. Which one of the following can be the charge carried by a body in terms of charge of an electron, e ?

A. $0.5e$

B. $5e$

C. $1/2e$ D. $6\frac{3}{4}e$

Hint: Charge exists as an integer multiple of the basic charge, e . Since it is quantized.

44. If a positively charged glass rod is brought closer to a neutral metallic sphere without physical contact, what charge will be observed on the closest side of the sphere?

A. Negative
B. Positive

C. Neutral

D. Can not be know

Hint: Induction gives rise to opposite charge.

45. When a glass rod is rubbed with a silk cloth, 0.5×10^{14} electrons are transferred from the silk to the rod. What charge is acquired by each body?

A. $6\mu\text{C}$ B. $8\mu\text{C}$ C. $3\mu\text{C}$ D. $5\mu\text{C}$

Solution:

$$Q = ne$$

$$Q = (0.5 \times 10^{14})(1.6 \times 10^{-19})$$

$$Q = 0.8 \times 10^{-5} \text{ C} = 8\mu\text{C}$$

Answer: B

46. Two metal spheres initially carrying charges of $-3\mu\text{C}$ and $7\mu\text{C}$ are made to contact and then separated. What is the number of electrons gained or lost after the process?

A. 3×10^5 B. 2×10^5 C. 1×10^5 D. 1.2×10^5

Solution:

$$Q = \frac{Q_1 + Q_2}{2} = \frac{-3 + (7)}{2} = 2\mu\text{C}$$

$$\text{and, } Q = ne \Rightarrow n = \frac{Q}{e}$$

$$n = \frac{2 \times 10^{-6}}{1.6 \times 10^{-19}} = 1.25 \times 10^5 \text{ electrons}$$

Answer: D

47. If a $3.2 \times 10^{-14} \text{ kg}$ oil drop is balanced by an electric field of $2 \times 10^6 \text{ N/C}$, then what is the charge on the drop

A. $-1.6 \times 10^{-18} \text{ C}$ B. $1.6 \times 10^{-18} \text{ C}$ C. $-1.6 \times 10^{-19} \text{ C}$ D. $1.6 \times 10^{-19} \text{ C}$

Solution:

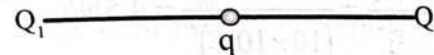
$$Eq = mg$$

$$q = \frac{mg}{E} = \frac{(3.2 \times 10^{-14})(10)}{2 \times 10^6}$$

$$= 1.6 \times 10^{-19} \text{ C}$$

Answer: D

48. If the net electrostatic force on q is zero, what can be said about Q_1 and Q_2 ?

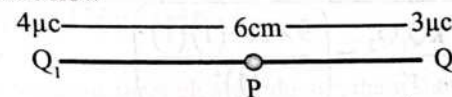


- A. Q_1 and Q_2 are unequal in magnitude and opposite in sign
B. Q_1 and Q_2 are unequal in magnitude and the same in sign
C. Q_1 and Q_2 are equal in magnitude and the same in sign
D. Q_1 and Q_2 are equal in magnitude and opposite in sign

Hint: Use law of electrostatic and coulomb's law

Answer: B

49. What is the net electric field strength mid way between the two point charges shown below

A. $1 \times 10^7 \text{ N/C}$ to the rightC. $1 \times 10^7 \text{ N/C}$ to the leftB. $2 \times 10^7 \text{ N/C}$ to the rightD. $2 \times 10^7 \text{ N/C}$ to the left

Solution:

$$E_p = E_1 - E_2 = \frac{kQ_1}{r_1^2} - \frac{kQ_2}{r_2^2} = \frac{k}{r^2} [Q_1 - Q_2]$$

$$E_p = \frac{9 \times 10^9}{(3 \times 10^{-2})^2} [4 \times 10^{-6} - 3 \times 10^{-6}]$$

$$E_p = 1 \times 10^7 \text{ N/C, to the right.}$$

50. If the electric field strength 3cm from a point charge is 50N/c, What will be the field strength at a distance of 10cm from this charge?
- A. 5N/c B. 4.5N/c C. 500N/c D. 15N/c

Solution:

$$E_1 = \frac{kQ}{r_1^2} = 50$$

$$kQ = (50)(r_1^2) = (50)(3 \times 10^{-2})^2 = 45 \times 10^{-3}$$

$$E_2 = \frac{kQ}{r_2^2} = \frac{45 \times 10^{-3}}{(10 \times 10^{-2})^2} = 4.5 \text{ N/c}$$

Answer: B

51. What is the electrostatic force between two identical point charges of each 1c separated by a distance of 1cm?

- A. $0.09 \times 10^9 \text{ N}$ B. $0.9 \times 10^9 \text{ N}$ C. $9 \times 10^9 \text{ N}$ D. $90 \times 10^9 \text{ N}$

Solution:

$$F = \frac{kQ_1Q_2}{r^2} = \left(\frac{9 \times 10^9 (1)(1)}{(1)^2} \right)$$

$$= 9 \times 10^9 \text{ N}$$

Answer: C

52. The electrostatic force between two point charges is $8 \times 10^{-5} \text{ N}$. What will be the force between these point charges if their separation is halved?
- A. $8 \times 10^{-5} \text{ N}$ B. $3.2 \times 10^{-5} \text{ N}$ C. $3.2 \times 10^{-4} \text{ N}$ D. $8 \times 10^{-4} \text{ N}$

Solution:

$$F_1 = \frac{kQ_1Q_2}{r_1^2} = 8 \times 10^{-4} \text{ N}$$

$$F_2 = \frac{kQ_1Q_2}{r_2^2}, r_2 = \frac{1}{2} r_1$$

$$F_2 = \frac{kQ_1Q_2}{\left(\frac{1}{2} r_1\right)^2} = 4 \left(\frac{kQ_1Q_2}{r_1^2} \right) = 4F_1 = 4(8 \times 10^{-5})$$

$$F_2 = 3.2 \times 10^{-4} \text{ N}$$

Answer: C

53. What is the electric field strength at a distance of 3mm from a $3 \mu\text{C}$ point charges?

- A. $3 \times 10^9 \text{ N/c}$ B. $6 \times 10^9 \text{ N/c}$ C. $9 \times 10^9 \text{ N/c}$ D. $4 \times 10^9 \text{ N/c}$

Solution:

$$E = \frac{kQ}{r^2} = \frac{(9 \times 10^9)(3 \times 10^{-6})}{(3 \times 10^{-3})^2}$$

$$= 3 \times 10^9 \text{ N/c}$$

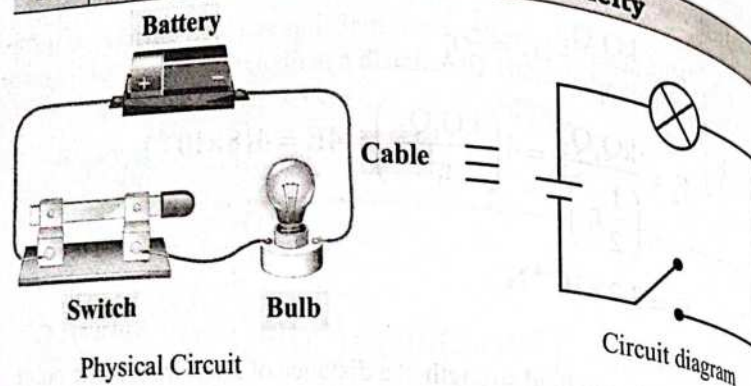
Answer: A

9.7 Electric Circuits

For the flow of electrons through a conductor, there should be a complete path, and this path is known as *circuit*.

Electric Circuit: Is a path way through which charged particles can flow to give a defined purpose.

A typical electric circuit consists of connecting cables, voltage source, load resistor such as a light bulb to dispat energy and a switch to close or open the system as shown below:



- ☑ When the switch is ON, charge flows through the circuit and hence there is current. And, when the switch is OFF, the circuit will not have current.

Some of the circuit elements with their symbols and purposes are given below

Circuit Element	Symbol	Use
Bulb		Give Light
Electric Cell		Drive Charges
Switch		ON, OFF
Resistor		Disppate Energy
Ammeter		Measure Current
Voltmeter		Measure Voltage

Illustrative Examples

54. What is an electric circuit?

Explanation:

It is a complete path for the flow of electrons through a conductor to get

light, heat, sound,...etc. from electric energy.

55. What are the basic circuit, elements?

Explanation:

Cable, electric source such as dry cell, switch, external resistor such as bulb, heater,...etc.

Match the items in column 'A' with those in column 'B'

A

56. Bulb

57. Dry Cell

58. Switch

59. Resistor

60. Ammeter

61. Voltmeter

B

a.

b.

c.

d.

e.

f.

Answers

56.f

57.e

58.d

59.c

60.b

71.a

9.8 Current, Voltage and Ohm's Law

Here, we are going to define current and voltage and state ohm's law

Electric current

The flow of charged particles through a conductor is called *current*

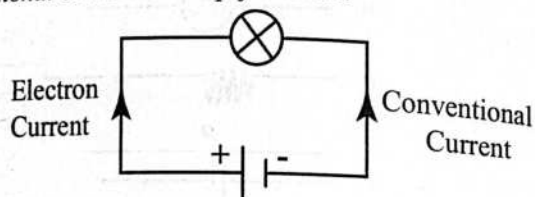
Electric Current: Is the flow of charge across a given cross-sectional area of a conductor per unit time

$$\text{Electric Current} = \frac{\text{Flow of Charge}}{\text{Time Taken}}$$

$$I = \frac{\Delta Q}{\Delta t}$$

Electric current is a scalar quantity and its SI Unit is the ampere, (A).
 $1A = \frac{1C}{s}$

Current is of two types, electron current and conventional current.
 ✓ The flow of electrons from the negative terminal to the positive terminal of a battery is called *electron current*. And, the "flow" of protons from the positive terminal to the negative terminal of battery is called *conventional current* or simply current.



Illustrative Example

62. What is electric current?

Explanation:

It is the flow of charges per unit time

63. What is the difference between electron current and conventional current?

Explanation:

Electron current is the flow of electrons from negative to positive terminal of a battery. While, conventional current is the "flow" of protons from the positive to the negative terminal of the battery.

64. What device is used to measure electric current?

Explanation:

Ammeter, Galvanometer and Multimeter can measure current in a circuit.

65. What is the current in a circuit where $60\mu C$ charge flows in 0.006 seconds?

Solution:

$$I = \frac{Q}{t} = \frac{60 \times 10^{-6}}{6 \times 10^{-3}} = 0.01A$$

66. What is the amount of charge in a wire if 0.5A current is recorded flowing for 10 seconds?

Solution:

$$I = \frac{\Delta Q}{\Delta t} \Rightarrow \Delta Q = I \Delta t$$

$$\Delta Q = (0.5)(10) = 5C$$

67. If 5×10^{22} electrons pass through a wire in 200 seconds, What is the current in the wire?

Solution:

$$I = \frac{\Delta Q}{\Delta t} = \frac{ne}{\Delta t}$$

$$I = \frac{(5 \times 10^{22})(1.6 \times 10^{-19})}{200}$$

$$= 40A$$

Voltage

Voltage, also known as *potential difference* is the agent that drives electrons to flow through a conductor.

Voltage: Is the work done per unit charge needed to move a test charge from one point to the other.

$$\text{Voltage} = \frac{\text{Work done}}{\text{Charge}}$$

$$V = \frac{W}{Q}$$

Voltage or potential difference is a scalar quantity, and its SI unit is the volt(V) $1V = 1 \frac{J}{C}$

✓ Voltage is measured using an instrument called Voltmeter.

Illustrative Examples

68. What is the potential difference in moving a 3c charge with a 360J of work done?

Solution:

$$V = \frac{W}{Q} = \frac{360}{3}$$

$$= 120V$$

69. What charge is moved across a potential difference of 12V using a work done of 600J?

Solution:

$$V = \frac{W}{Q} \Rightarrow Q = \frac{W}{V}$$

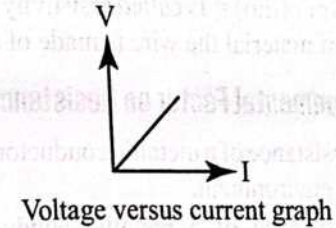
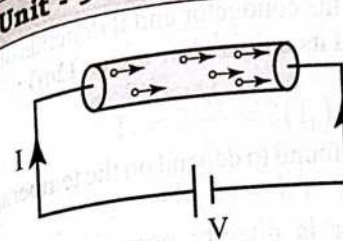
$$Q = \frac{600}{12}$$

$$Q = 50C$$

Ohm's Law

The relationship between voltage and current was discovered by George Simon Ohm and is stated as follows,

Ohm's Law States that: The current flowing through a conductor is directly proportional to the potential difference supplied across the ends of the conductor.



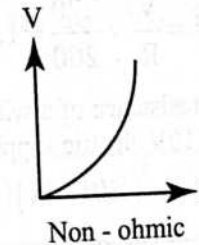
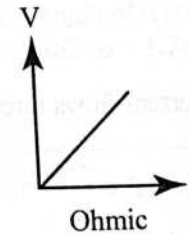
$$V = IR \rightarrow \text{Ohm's Law}$$

And, The slope of the V - I current is resistance, $R = \frac{V}{I}$

Where: R = Resistance of the conductor and its SI unit is the ohm(Ω)

$$1\Omega = \frac{1V}{A}$$

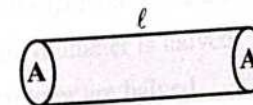
Materials that obey ohm's law are said to be ohmic materials and their V - I graph is straight line. While non-ohmic materials have no linear V - I graph as shown below:



- ✓ Resistance is the measure of difficulty electrons face to flow through a material. The resistance of a metallic conductor is found to be dependent on its geometrical features.
- ✓ Resistance is directly proportional to the length and inversely proportional to the cross sectional area of wire

$$R \sim \frac{\ell}{A}$$

$$R = \rho \frac{\ell}{A}$$



Where: ρ (rho) = Is called resistivity of the conductor and it depends on the type of material the wire is made of and its unit is ohm-meter (Ωm)

Environmental Factor on Resistance

The resistance of a metallic conductor is found to depend on the temperature of the environment.

- ☑ Resistance of a metallic conductor is directly proportional to the temperature of the environment, ΔT and its original resistance, R_o

$$\Delta R \sim \Delta T R_o$$

$$\Delta R = \alpha R_o \Delta T$$

Where: α (alpha) = Is coefficient of thermal resistivity.

Illustrative Examples

70. What electric current flows through a 200Ω light bulb subjected to a 220V voltage?

Solution:

$$I = \frac{V}{R} = \frac{220}{200} = 1.1\text{A}$$

71. What is the resistance of a wire if a 2A current flows through it when plugged to a 110V electric supply?

Solution:

$$R = \frac{V}{I} = \frac{110}{2}$$

$$R = 55\Omega$$

72. A current of 2A flows through an ohmic wire of resistance 10Ω . What current will flow through the wire if the potential difference is doubled?

Solution:

$$I_1 = \frac{V}{R} = 2$$

$$I_2 = \frac{V_2}{R}, V_2 = 2V_1$$

$$I_2 = 2 \frac{V_1}{R} = 2(I_1)$$

$$= 2(2) = 4\text{A}$$

73. What is the resistance of a 2m metallic wire of diameter 10mm and resistivity $1.84 \times 10^{-4} \Omega\text{m}$?

Solution:

$$R = \frac{\rho \ell}{A}, A = \pi r^2 = (3.14)(5 \times 10^{-3})^2$$

$$R = \frac{(1.84 \times 10^{-4})(2)}{7.85 \times 10^{-5}}$$

$$R = \frac{3.68 \times 10^{-4}}{7.85 \times 10^{-5}} = 4.7\Omega$$

74. What is the length of a copper wire with a diameter of 20mm and resistance 110Ω ($\rho = 1.7 \times 10^{-8} \Omega\text{m}$)

Solution:

$$R = \frac{\rho \ell}{A}, A = \pi r^2 = (3.14)(10 \times 10^{-3})^2 = 314 \times 10^{-6}$$

$$\ell = \frac{RA}{\rho} = \frac{(110)(3.14 \times 10^{-4})}{1.7 \times 10^{-8}}$$

$$= 2 \times 10^6 \text{m}$$

75. What will be the resistance of a wire of initial resistance 100Ω . After its
- Length is halved and diameter doubled
 - Length is double and diameter is halved
 - Both length and diameter are halved
 - Both length and diameter are doubled

Solution:

$$\text{use, } R_1 = \frac{\rho \ell_1}{A_1}, A = \pi r_1^2$$

$$A. R_2 = \frac{\rho \ell_2}{A_2}, A_2 = \pi r_2^2 = 4\pi r_1^2$$

$$R_2 = \frac{\rho \left(\frac{1}{2} \ell_1 \right)}{4\pi r_1^2} = \frac{1}{8} R_1 = \frac{100}{8} = 12.5 \Omega$$

$$B. R_2 = \frac{\rho \ell_2}{A_2}, A_2 = \pi r_2^2 = \frac{1}{4} \pi r_1^2$$

$$R_2 = \frac{\rho \left(\frac{1}{2} \ell_1 \right)}{\frac{1}{4} \pi r_1^2} = 8 R_1 = 8(100) = 800 \Omega$$

$$C. R_2 = \frac{\rho \ell_2}{A_2}, A_2 = \pi r_2^2 = \frac{1}{4} \pi r_1^2$$

$$R_2 = \frac{\rho (2\ell_1)}{\frac{1}{4} \pi r_1^2} = 2 R_1 = 2(100) = 200 \Omega$$

$$D. R_2 = \frac{\rho \ell_2}{A_2}, A_2 = \pi r_2^2 = 4\pi r_1^2$$

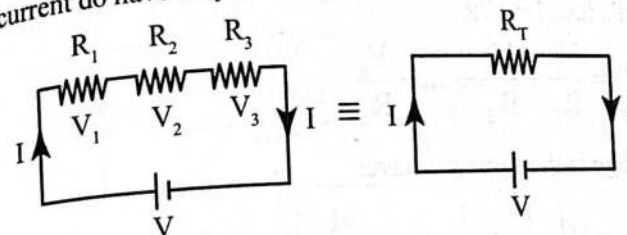
$$R_2 = \frac{\rho (2\ell_1)}{4\pi r_1^2} = \frac{1}{2} R_1 = \frac{100}{2} = 50 \Omega$$

9.9 Combination of Resistors

In a circuit, resistors may be connected in series, in parallel or in both based on the requirement.

Resistors in Series

When resistors are connected in series, they are joined one after the other and the current do have only one single path in the circuit as shown below;



The current that passes through each resistor is the same as the total current in the circuit.

$$I_1 = I_2 = I_n = I_T = I$$

And, the total potential drop in the circuit is the sum of the potential drops across each resistor.

$$V_T = V_1 + V_2 + \dots + V_n$$

From ohm's law, $V = IR$

$$I_T R_T = I_1 R_1 + I_2 R_2 + \dots + I_n R_n$$

Since current is the same, we have

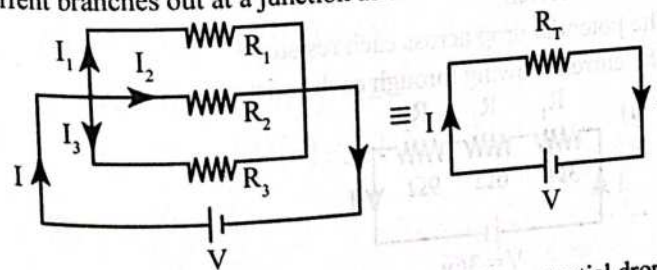
$$I(R_T) = I(R_1 + R_2 + \dots + R_n)$$

Therefore, the total or equivalent resistance when resistors are connected in series is obtained by

$$R_T = R_1 + R_2 + \dots + R_n$$

Resistors in Parallel

When resistors are connected in parallel, they are joined face to face and the current branches out at a junction as shown below



The potential drop in the network is the same as the potential drops across each resistor.

$$V_1 = V_2 = V_n = V_T = V$$

And, the total current in the system is the sum of the current that flow through each resistor,

$$I_T = I_1 + I_2 + \dots + I_n$$

From ohm's law, $I = V/R$

$$\frac{V_T}{R_T} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots + \frac{V_n}{R_n}$$

Since voltage is the same, we have;

$$\frac{V}{R_T} = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n} \right)$$

Therefore, the total or equivalent resistance in parallel connection is obtained by:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

Illustrative Example

76. In which combination of resistors will the total resistance

A. Increase

B. Decrease

Explanation:

A. In series combination

B. In parallel combination

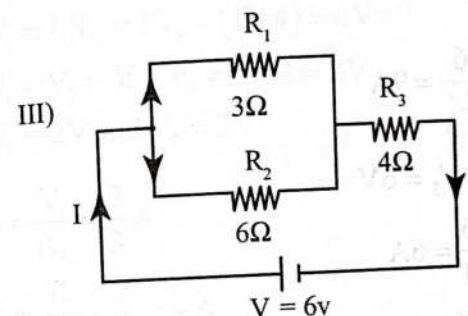
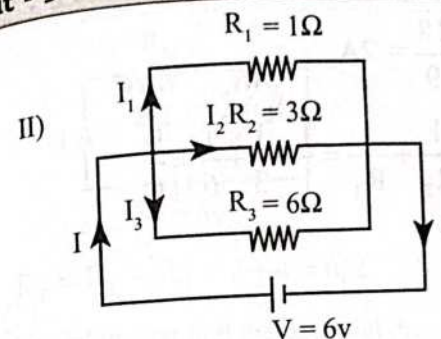
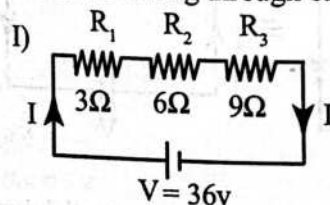
77. For the circuits shown below, find

A. The total resistance

B. The total current

C. The potential drop across each resistor

D. The current flowing through each resistor



Solution:

(i) A) $R_T = R_1 + R_2 + R_3$
 $R_T = 3 + 6 + 9 = 18\Omega$

B) $I = \frac{V}{R} = \frac{36}{18} = 2A$

C) $V_1 = IR_1 = (2)(3) = 6V$
 $V_2 = IR_2 = (2)(6) = 12V$
 $V_3 = IR_3 = (2)(9) = 18V$

D) $I_1 = \frac{V_1}{R_1} = \frac{6}{3} = 2A$

$I_2 = \frac{V_2}{R_2} = \frac{12}{6} = 2A$

$$I_3 = \frac{V_3}{R_3} = \frac{18}{9} = 2A$$

$$(ii) A) \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{1} + \frac{1}{3} + \frac{1}{6} = \frac{9}{6}$$

$$\frac{1}{R_T} = \frac{3}{2}$$

$$R_T = \frac{2}{3} \Omega$$

$$B) I = \frac{V}{R} = \frac{6}{\frac{2}{3}} = 9A$$

$$C) V_1 = V_2 = V_3 = 6V$$

$$D) I_1 = \frac{V_1}{R_1} = \frac{6}{1} = 6A$$

$$I_2 = \frac{V_2}{R_2} = \frac{6}{3} = 2A$$

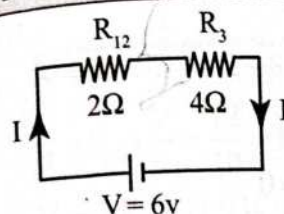
$$I_3 = \frac{V_3}{R_3} = \frac{6}{6} = 1A$$

(iii) A) R_1 and R_2 are in parallel

$$\frac{1}{R_{12}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{3} + \frac{1}{6} = \frac{1}{2} = 2\Omega$$

R_{12} and R_3 become in series

$$B) I = \frac{V}{R} = \frac{6}{6} = 1A$$



$$R_T = R_{12} + R_3 = 2 + 4 = 6\Omega$$

C) Now, let us first find the potential drop across R_3

$$V_3 = I_3 R_3 = IR_3 = (1)(4) = 4V$$

$$V_1 = V_2 = V - V_3 = 6 - 4 = 2V$$

$$V_1 = 2V \text{ and } V_2 = 2V$$

$$D) I_1 = \frac{V_1}{R_1} = \frac{2}{3} A$$

$$I_2 = \frac{V_2}{R_2} = \frac{2}{6} = \frac{1}{3} A$$

$$I_3 = \frac{V_3}{R_3} = \frac{4}{4} = 1A$$

78. The equivalent resistance of two resistors is 7Ω when connected in series and it is $10/7\Omega$. When they are in parallel. What is the resistance of each resistor?

Solution:

$$R = R_1 + R_2 = 7, \text{ in series.}$$

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{10}{7}, \text{ in parallel.}$$

from, $R_1 + R_2 = 7 \Rightarrow R_2 = 7 - R_1$. Substitute this into

$$\frac{R_1 R_2}{R_1 + R_2} = \frac{10}{7}$$

$$\frac{R_1(7-R_1)}{7} = \frac{10}{7}$$

$$7R_1 - R_1^2 = 10$$

$$R_1^2 - 7R_1 + 10 = 0$$

Use the quadratic equation to solve for R_1

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$R_1 = \frac{7 \pm \sqrt{(-7)^2 - 4(1)(10)}}{2(1)} = \frac{7 \pm 3}{2}$$

$$R_1 = \frac{7+3}{2} = 5\Omega \text{ or } R_1 = \frac{7-3}{2} = 2\Omega$$

When, $R_1 = 5\Omega$, $R_2 = 2\Omega$, and when $R_1 = 2\Omega$, or $R_2 = 5\Omega$

79. A wire of resistance R is cut into five equal pieces. If the pieces equivalent resistance when connected in parallel is 2Ω , what was the resistance of the original wire?

Solution:

We know, $R = \frac{\rho l}{A}$ And, when length decreases, resistance also decreases

So, each piece will have a resistance of $R/5$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{2} = \frac{1}{\frac{R}{5}} + \frac{1}{\frac{R}{5}} + \frac{1}{\frac{R}{5}} + \frac{1}{\frac{R}{5}} + \frac{1}{\frac{R}{5}} = \frac{25}{R}$$

$$R = 50\Omega$$

80. Two resistors of $R_1 = 2\Omega$ and $R_2 = 8\Omega$ are connected in series with a 12V battery. What is the potential drop across each resistor when the switch is on?

Solution:

$$R = R_1 + R_2 = 2 + 8 = 10\Omega$$

$$I_1 = I_2 = \frac{V}{R} = \frac{12}{10} = 1.2A$$

$$V_1 = I_1 R_1 = (1.2)(2) = 2.4V$$

$$V_2 = I_2 R_2 = (1.2)(8) = 9.6V$$

81. Suppose a resistor is connected to a constant voltage supply. When will the current in the resistor decrease

- When length of the resistor increases
- When length of the resistance decreases
- When cross-sectional area of the resistor decreases
- When the resistance decreases

$$\text{Solution: } I = \frac{\rho l}{A} \text{ and } I = \frac{V}{R}$$

Answer: A

82. Consider a circuit with an emf of 4.5V and a load resistance of 40Ω and a current of 0.1A. What will be the current if additional cell of emf 4.5V is connected to the previous cell in series?

- 0.18A
- 0.05A
- 0.20A
- 0.21A

$$\text{Solution: } E_1 = I(R + r)$$

$$R + r = \frac{E_1}{I_1} = \frac{4.5}{0.1} = 45$$

$$r = 45 - R = 45 - 40 = 5\Omega$$

$$E_2 = 4.5 + 4.5 = 9V$$

$$R + r + r = \frac{E_2}{I_2}$$

$$I_2 = \frac{E_2}{R + r + r} = \frac{9}{40 + 5 + 5} = 0.18A$$

Answer: A

83. The correct way of connecting an Ammeter and a voltmeter in a circuit is?

- A. Both are connected in series with the resistor
- B. Both are connected in parallel with the resistor
- C. Ammeter is connected in series and voltmeter in parallel with the resistor
- D. Ammeter is connected in parallel and voltmeter in series with the resistor.

84. You are given three 1Ω resistors. All of the following resistance can be produced using all three EXCEPT?

- A. $1/3\Omega$
- B. 1.5Ω
- C. 1Ω
- D. 3Ω

Hint: All three in series, $R = 3\Omega$

All three in parallel, $R = 1/3\Omega$

Two in parallel, one series, $R = 1.5\Omega$

The in series, one parallel = $\frac{2}{3}\Omega$

Answer: C

85. When a 15V dry cell is connected to a load resistor of 144Ω , a current of 0.1A flows through the resistor. What is the internal resistance of the dry cell?

- A. 300Ω
- B. 150Ω
- C. 10Ω
- D. 6Ω

Solution:

$$R + r = \frac{E}{I} = \frac{15}{0.1} = 150\Omega$$

$$r = 150 - R = 150 - 144$$

$$= 6\Omega$$

Answer: D

86. A battery of emf 5V and internal resistance 10Ω is connected in series with an external resistor of resistance 240Ω . What is the potential drop on the load resistor?

- A. 0.2V
- B. 5.2V
- C. 4.8V
- D. 5V

Solution:

$$E = I(r + R)$$

$$I = \frac{E}{r + R} = \frac{5}{10 + 240}$$

$$= 0.02A$$

$$V_{\text{external}} = IR = (0.02)(240)$$

$$= 4.8V$$

Answer: C

87. In an experiment four resistors 3Ω , 4Ω , 12Ω , and 16Ω are required at different time to give 1.7Ω . But, the lab technician told you to use only two resistors. Which two resistors will you choose to do the experiment?

- A. 3Ω and 6Ω
- B. 3Ω and 4Ω
- C. 4Ω and 12Ω
- D. 4Ω and 16Ω

Hint:

$$\frac{1}{R} = \frac{1}{3} + \frac{1}{4} = \frac{7}{12}$$

$$R = \frac{12}{7} = 1.7\Omega$$

Answer: B

88. The terminal p.d of a battery is maximum when

- A. The emf is minimum
- B. The battery is being discharged
- C. There is no current flowing
- D. There is a steady current flow

Answer: C

Hint: $E = V_{\text{int}} + V_{\text{ext}}$

89. A lighting protection provided to a building is

- A. An overhead grid of insulators extended to the ground
- B. An overhead grid of wire extended to the ground
- C. A system of lighting rod extended to the building
- D. Stem of lighting rods connected to the clouds

Answer: B

90. What is the resistance of copper wire of length 30m length and 0.8cm radius ($\rho_{\text{Cu}} = 1.7 \times 10^{-8}\Omega\text{m}$)

- A. 2Ω
- B. 1Ω
- C. 0.5Ω
- D. 0.25Ω

Solution:

$$R = \frac{\rho l}{A} = (1.7 \times 10^{-8}) \left(\frac{30}{201 \times 10^{-8}} \right) = 0.25 \Omega$$

91. What length of wire of resistivity $8 \times 10^{-7} \Omega \text{m}$ and cross-sectional area 0.2mm^2 is required to get a resistance of 10Ω ?
 A. 50m B. 25m C. 10m D. 5m

Solution:

$$R = \frac{\rho l}{A} \Rightarrow l = \frac{RA}{\rho} = \frac{(10)(0.2 \times 10^{-6})}{8 \times 10^{-7}} = 25 \text{m}$$

92. A metal rod of 1mm diameter has a resistance of 0.01Ω . What would be the resistance of the rod if the diameter were doubled?
 A. 0.1Ω B. 0.5Ω C. 0.0025Ω D. 0.25Ω

Hint: $R_1 = \frac{\rho l}{A_1} = \frac{\rho l}{\pi d_1^2 / 4} = 0.01$

$$R_2 = \frac{\rho l}{A_2} = \frac{\rho l}{\pi d_2^2 / 4} = \frac{\rho l}{4\pi d_1^2 / 4} = \frac{R_1}{4} = \frac{0.01}{4} = 0.0025 \Omega$$

93. A potential difference of 5.1V is applied across a 2m long copper wire of cross-sectional area 0.01mm^2 . What is the current flowing through the wire? ($\rho = 1.7 \times 10^{-8} \Omega \text{m}$)
 A. 5.1A B. 4.1A C. 3.1A D. 1.5A

Solution:

$$I = \frac{V}{R} = \frac{V}{\frac{\rho l}{A}} = \frac{AV}{\rho l}$$

$$I = \frac{(10^{-8})(5.1)}{(1.7 \times 10^{-8})(2)} = 1.5 \text{A}$$

Answer: D

94. When a potential difference of 6V is applied across a brass wire of cross-sectional area 0.02cm^2 , a current of 12A flows through it. What is the length of the wire? ($\rho = 6.6 \times 10^{-8} \Omega \text{m}$)
 A. 15.2m B. 5.2m C. 10.2m D. 6.2m

Solution:

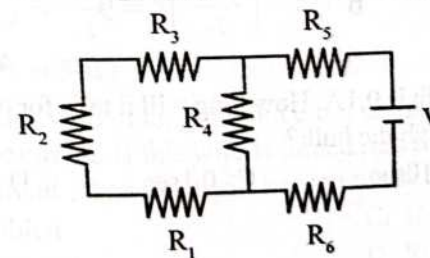
$$R = \frac{V}{I} = \frac{6}{12} = 0.5 \Omega$$

$$R = \frac{\rho l}{A} \Rightarrow l = \frac{RA}{\rho}$$

$$l = \frac{(0.5)(0.02 \times 10^{-4})}{6.6 \times 10^{-8}} = 15.2 \text{m}$$

Answer: A

95. Six identical resistors of each 4Ω are connected in a circuit as shown below. What is the total resistance of the circuit?
 A. 6Ω B. 10Ω C. 12Ω D. 11Ω



Solution:

R_1, R_2 and R_3 are in series, hence

$$R_{123} = R_1 + R_2 + R_3 = 4 + 4 + 4 = 12 \Omega$$

And, R_{123} is in parallel with R_4

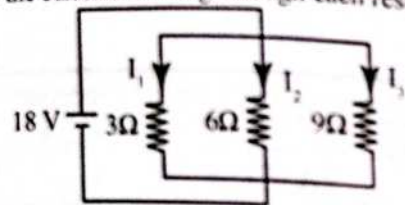
$$\frac{1}{R_{1234}} = \frac{1}{R_{123}} + \frac{1}{R_4} = \frac{1}{12} + \frac{1}{4} = \frac{1}{3}$$

$$R_{123} = 3\Omega$$

And, R_{1234} , R_5 and R_6 are in series.

$$R = R_{1234} + R_5 + R_6 = 3 + 4 + 4 = 11\Omega$$

96. What are the currents flowing through each resistor shown below Answer: D



- A. $I_1 = 6A, I_2 = 2A, I_3 = 3A$
 B. $I_1 = 6A, I_2 = 3A, I_3 = 2A$
 C. $I_1 = 3A, I_2 = 6A, I_3 = 2A$
 D. $I_1 = 3A, I_2 = 2A, I_3 = 6A$

Solution:

$$I_1 = \frac{18}{3} = 6A, \quad I_2 = \frac{18}{6} = 3A, \quad I_3 = \frac{18}{9} = 2A$$

97. A current in a torch bulb is 0.1A. How long will it take for one coulomb of charge to pass through the bulb? Answer: B

- A. 5sec B. 10sec C. 0.1sec D. 1sec

Solution:

$$t = \frac{Q}{I} = \frac{1}{0.1} = 10\text{sec}$$

98. A current of one ampere corresponds to the flow of one coulomb of charge Answer: B

- A. In one second C. In a uniform electric field
 B. Across a one ohm resistor D. Across one volt P.d

Hint:

$$\text{Current} = \frac{\text{Charge}}{\text{Time}}$$

$$1A = \frac{1C}{S}$$

Answer: A

99. For an electric current in a wire

- A. The direction of current and direction of flow of electrons are opposite
 B. The electric current in the wire is due to the random motion of its electron
 C. The electric current in the wire is due to the perpendicular motion of its electrons.
 D. Electrons flow in the same direction as the conventional current.

Hint: Conventional current is opposite in direction to the electron current.

Answer: A

100. A wire of length 1m and 2mm diameter has a resistance of 6Ω . What will be the resistance of this wire if its length become 5m, keeping all other factors constant?

- A. 6Ω B. 5Ω C. 30Ω D. 60Ω

Hint: $R_1 = \frac{\rho \ell_1}{A} = 6$

$$R_2 = \frac{\rho \ell_2}{A} = 5 \left(\frac{\rho \ell_1}{A} \right) = 5(6) = 30\Omega$$

Answer: C

101. A resistor wire of length ℓ and cross sectional area A is connected in a simple circuit. If this wire is folded into two and connected in the same circuit, then what will happen to the circuit resistance?

- A. Doubled C. Halved
 B. Quartered D. Remains the same

Hint: $R_1 = \frac{\rho \ell_1}{A_1}$

$$R_2 = \frac{\rho \ell_2}{A_2} = \frac{\rho \left(\frac{1}{2} \ell_1 \right)}{(2A_1)} = \frac{1}{4} \frac{\rho \ell_1}{A_1}$$

$$= \frac{1}{4} R_1$$

Answer: B

102. An electric cell supplies 0.9A current through a 2Ω load resistor and a current of 0.3A through a 7Ω load resistor. What is the internal resistance of the cell?
- A. 2Ω B. 1Ω C. 1.2Ω D. 0.5Ω

Solution:

$$E_1 = E_2$$

$$I_1(R_1 + r) = I_2(R_2 + r)$$

$$0.9(2 + r) = 0.3(7 + r)$$

$$1.8 + 0.9r = 2.1 + 0.3r$$

$$0.6r = 0.3$$

$$r = 0.5\Omega$$

Answer: D

103. Potential difference of an electric cell in an open circuit is 6V but it falls to 4V when a current of 2A is flowing through it. What is internal resistance of the cell?

- A. 2Ω B. 1Ω C. 3Ω D. 4Ω

Solution:

$$E = V_{\text{int}} + V_{\text{ext}}$$

$$6 = V_{\text{int}} + 4$$

$$V_{\text{int}} = 2$$

$$1r = 2$$

$$2r = 2$$

$$r = 1\Omega$$

Answer: A

104. Ten identical resistors each having a resistance of 1Ω are connected in parallel. What is the equivalent resistance of the network?
- A. 10Ω B. 1Ω C. 0.1Ω D. 0.01Ω

Solution:

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{10}{R}$$

$$R_T = \frac{R}{10} = \frac{1}{10}$$

$$R_T = 0.1\Omega$$

Answer: C

105. A wire of resistance R is cut into n equal parts. These parts are then connected in parallel. Then equivalent resistance of the combination is
- A. nR B. R/n C. n/R D. R/n²

Solution:

$$\frac{1}{R_T} = \frac{1}{R/n} + \frac{1}{R/n} + \dots + \frac{1}{R/n}$$

$$\frac{1}{R_T} = \frac{n}{R/n} = \frac{n^2}{R}$$

$$R_T = \frac{R}{n^2}$$

Answer: D

106. When both the length and cross-section area of a wire are doubled, its resistance will?

- A. Be halved C. Remain constant
B. Be double D. Be quartered

$$R_1 = \frac{\rho \ell_1}{A_1}, \text{ and } R_2 = \frac{\rho \ell_2}{A_2} = \frac{2\rho \ell_1}{2A_1} = \frac{\rho \ell_1}{A_1} = R_1$$

Hint:

$$R_2 = R_1$$

Answer: C

107. Three equal resistors are given. How many different combinations can be made from them?

- A. Three B. Four C. Five D. Six

Hint: They may be connected:

- All in series
- All in parallel
- Two in series and parallel with the third
- Two in parallel and series with the third

108. The resistance of a wire of uniform diameter 'd' and length ℓ is R. The resistance of another wire of the same material but diameter 2d and length 4 ℓ will be?

A. 2R

B. R

C. $\frac{R}{2}$ D. $\frac{R}{4}$

Hint: $R_1 = \rho \frac{\ell}{A} = \frac{\rho \ell}{\pi \left(\frac{d}{2}\right)^2} = 4 \frac{\rho \ell}{\pi d^2}$

$$R_2 = \frac{\rho(4\ell)}{\pi \left(\frac{2d}{2}\right)^2} = \frac{16}{4} \frac{\rho \ell}{\pi d^2} = 4 \frac{\rho \ell}{\pi d^2}$$

$$R_1 = R_2 = R$$

109. How many 2.1V electric cells with internal resistance of 0.2Ω each are to be connected in series to obtain a battery so that a conductor of resistance 6Ω would carry a current of 1.5A?

A. 4

B. 5

C. 6

D. 7

$$nE = I(nr + R)$$

Hint: $2.1n = 1.5(0.2n + 6) = 0.3n + 9$

$$1.8n = 9$$

$$n = 5$$

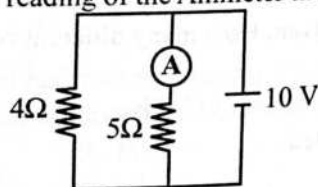
110. What is the reading of the Ammeter in the circuit shown below?

A. 4A

B. 5A

C. 3A

D. 2A



Answer: B

Hint: Since the resistors are in parallel, the potential drop across each resistor is the same.

$$I = \frac{V}{R} = \frac{10}{5} = 2A$$

Answer: D

111. Two resistors x and y are connected in parallel. Resistor x carries twice the current then that of resistor y, then:

A. The potential drop across x is twice that of y

B. The potential drop across x is half that across y

C. Resistor x has twice resistance that of y

D. Resistor x has half resistance that of y

Answer: D

Hint: $I = V/R$ and from the nature of combination of resistors.

112. When 5 resistance of identical resistance R are connected in parallel, the equivalent resistance will be

A. 5R

B. R/5

C. 5/R

D. 0.5R

Solution:

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$$

$$\frac{1}{R_T} = \frac{5}{R}$$

$$R_T = \frac{R}{5}$$

Answer: B

113. How many identical resistors should be connected in parallel to give an equivalent resistance of 60Ω

A. 6 Five ohm's

B. 12 six ohm's

C. 12 five ohm's

D. 12 four ohm's

Hint: $R_T = R + R + \dots + R$

$$R_T = nR$$

$$60 = nR$$

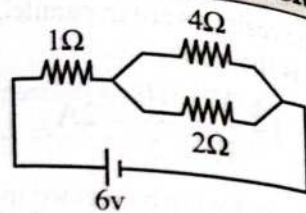
$$60 = (12)(5)$$

$$12 \text{ five ohms}$$

Answer: C

114. What is the current through the 2Ω resistor shown below.

- A. 7/12A
B. 12/7A
C. 12/5A
D. 5/12A



Hint: The 4Ω and the 2Ω are in parallel

$$\frac{1}{R_1} = \frac{1}{4} + \frac{1}{2} = \frac{3}{4} \Rightarrow R_1 = \frac{4}{3} \Omega$$

And, R_1 is in series with the 1Ω resistor.

$$R = R_1 + 1 = \frac{4}{3} + 1 = \frac{7}{3} \Omega$$

The current through the 1Ω is:

$$I_1 = \frac{V}{R} = \frac{6}{7/3} = \frac{18}{7} \text{ A}$$

The p.d across the 1Ω is:

$$V_1 = I_1 R_1 = \left(\frac{18}{7}\right) \left(\frac{4}{3}\right) = \frac{18}{7} \text{ V}$$

The p.d across the 4Ω and the 2Ω is equal to:

$$V_2 = V_4 = 6 - V_1 = 6 - \frac{18}{7} = \frac{24}{7} \text{ A}$$

The current through the 2Ω is:

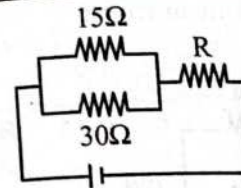
$$I_2 = \frac{V_2}{R_2} = \frac{24}{7/2} = \frac{24}{14} = \frac{12}{7} \text{ A}$$

Answer: B

115. Two resistors of 15Ω and 30Ω are connected in parallel what should be the value of to be connected on series with the two so that the net resistance will be 20Ω?

- A. 5Ω B. 10Ω C. 15Ω D. 6Ω

Hint: The circuit is of the form:

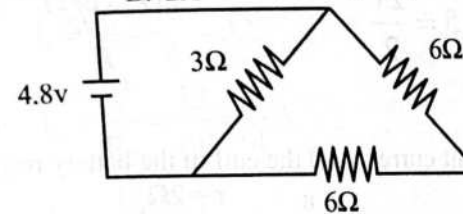


$$\frac{1}{R_1} = \frac{1}{15} + \frac{1}{30} = \frac{1}{10} \Rightarrow R_1 = 10 \Omega$$

$$R_T = R_1 + R \Rightarrow 20 = 10 + R = 10 \Omega \text{ Answer: B}$$

116. What is the current flowing in the circuit shown below

- A. 1A B. 2A C. 3A D. 4A



Hint: The two 6Ω resistors are in series

$$R_1 = 6 + 6 = 12 \Omega$$

R_1 and 3 resistors are in parallel

$$\frac{1}{R} = \frac{1}{3} + \frac{1}{R_1} = \frac{1}{3} + \frac{1}{12} = \frac{5}{12}$$

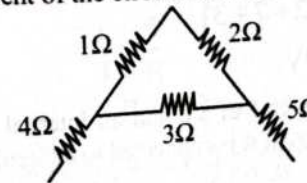
$$R = \frac{12}{5} = 2.4 \Omega$$

$$I = \frac{V}{R} = \frac{4.8}{2.4} = 2 \text{ A}$$

Answer: B

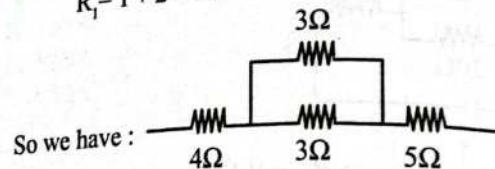
117. What is the equivalent of the circuit shown below :

- A. 5Ω
B. 10.5Ω
C. 5.1Ω
D. 6.5Ω



Hint: The 1Ω and 2Ω resistors are in series

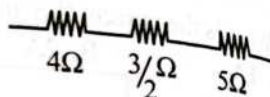
$$R_1 = 1 + 2 = 3\Omega$$



The two 3Ω resistors are in parallel

$$\frac{1}{R_2} = \frac{1}{3} + \frac{1}{3} = \frac{2}{3} \Rightarrow R_2 = \frac{3}{2}\Omega$$

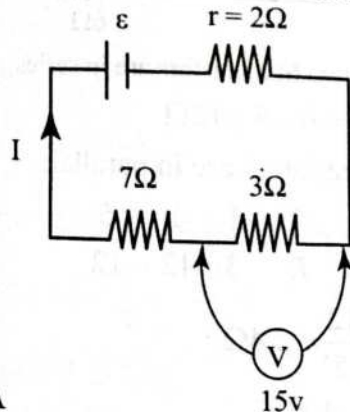
$$R_T = 4 + \frac{3}{2} + 5 = \frac{21}{2} = 10.5\Omega$$



118. What are the circuit current and the emf of the battery respectively

Answer: B

- A. 60A, 5V
B. 3A, 60V
C. 5A, 60V
D. 6A, 60V



Hint: $I = \frac{15}{3} = 5A$

$$E = I(r + 7 + 3)$$

$$E = 5(2 + 7 + 3) = 60V$$

119. A battery has an emf of 3V and an internal resistance of 1Ω . What current will it give if it is connected to a circuit of 4Ω resistor?
- A. 0.6A
B. 0.3A
C. 0.2A
D. 0.7A

Answer: C

Hint: $E = I(r + R)$

$$I = \frac{E}{r + R} = \frac{3}{1 + 4} = \frac{3}{5} = 0.6A$$

Answer: A

120. By what factor will the current in a circuit change when a battery of 12V initially connected to a 4Ω resistor is subjected to a load resistor of 48Ω ?
- A. 8
B. 4
C. 1/8
D. 1/12

Solution:

$$I_1 = \frac{V}{R} = \frac{12}{4} = 3A$$

$$I_2 = \frac{V}{R_2} = \frac{12}{48} = \frac{1}{4}A$$

$$\frac{I_2}{I_1} = \frac{1/4}{3} = \frac{1}{12}$$

Answer: D

121. If the equivalent resistance of two identical resistors is 4Ω when they are connected in parallel, then what will be their equivalent resistance when they are connected in series?
- A. 16Ω
B. 0.5Ω
C. 0.25Ω
D. 8Ω

Solution:

In series, $R_T = R + R = 8 + 8 = 16\Omega$

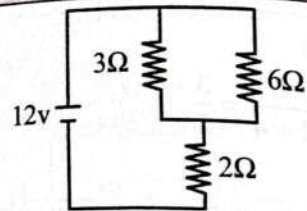
In parallel, $\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$

$$\frac{1}{4} = \frac{2}{R}$$

$$R = 8\Omega$$

Answer: A

122. For the circuit shown below, what is the current flowing through the 3Ω resistor?



- A. 1A B. 2A C. 3A D. 4A

Hint: The 3Ω and the 6Ω are in parallel and their resultant is 2Ω and this is in series with the 2Ω . The total resistance of the circuit is 4Ω .

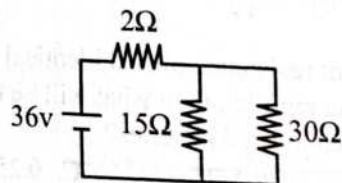
$$\text{Total current} = \frac{12}{4} = 3\text{A}$$

Voltage across the 2Ω is then 6V, which leaves 6V to the 3Ω and 6Ω resistors.

$$I_3 = \frac{V_3}{R_3} = \frac{6}{3} = 2\text{A}$$

123. For the circuit shown below, what is the current flowing through the 30Ω resistor?

Answer: B



- A. 1A B. 2A C. 3A D. 4A

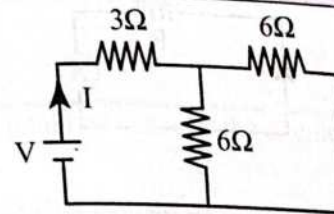
Hint: The 15Ω and 30Ω resistors are in parallel and their equivalent resistance is 10Ω and it gives a total circuit resistance of 12Ω .

$$\text{Total current} = \frac{36}{12} = 3\text{A}$$

Potential drop across the 2Ω is 6V and leaves the 30V to the 15Ω and 30Ω resistors $I_{30} = \frac{V_{30}}{R_{30}} = \frac{30}{30} = 1\text{A}$

Answer: A

124. For the circuit shown below, if the current in the circuit is 2A. What is the voltage supplied to the circuit?

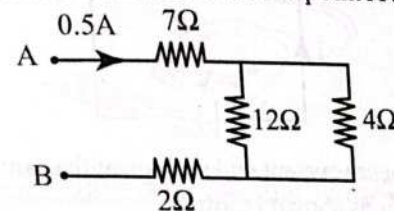


- A. 3V B. 6V C. 9V D. 12V

Hint: The two 6Ω resistors are in parallel and their equivalent resistance is 3Ω and gives a total circuit resistance of 6Ω when added to the 3Ω resistor in series. $V = IR = (2)(6) = 12\text{V}$

Answer: D

125. What is the potential difference between point A and B



- A. 3V B. 6V C. 9V D. 12V

Hint: The 4Ω and the 12Ω are in parallel and their equivalent resistance is 3Ω which is then in series with the 7Ω and 2Ω resistors. And, gives a total resistance of 12Ω .

$$V = IR = (0.5)(12) = 6\text{V}$$

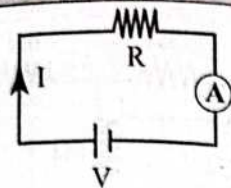
Answer: B

9.10 Voltmeter And Ammeter

The most common electric property measuring devices are ammeter and voltmeter.

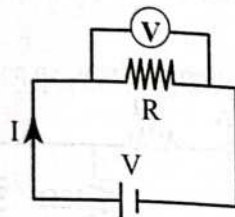
Ammeter: Is a current measuring device with a very small resistance.

Ammeter has a circuit symbol of  and is connected in series with the resistor

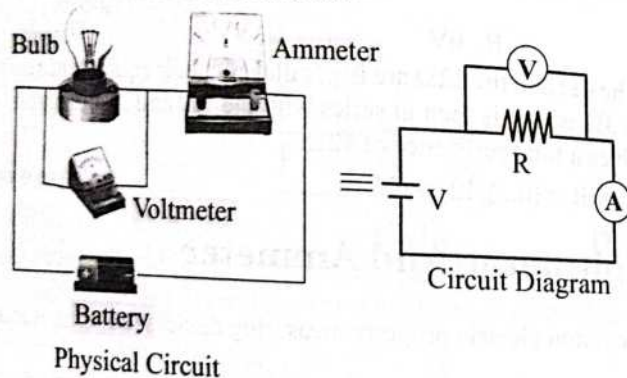


Voltmeter: Is a voltage measuring device with a very large resistance.

Voltmeter has a circuit symbol of V and is connected in parallel with the resistor



When we want to measure current and voltage at the same time, we connect ammeter and voltmeter as shown below



Conceptual Example

126. What will happen if ammeter is connected in parallel with the resistor?

Explanation:

It would draw most of the current and will get damage.

127. What will happen is voltmeter is connected in series with the

resistor?

Explanation:

It will increase the total resistance of the circuit and no current will flow in the circuit.

To measure different electric properties, we use multimeter.

Multimeter: Is a current, voltage and resistance measuring device.



Multimeter

Illustrative Example

Match the item in column A with those in column B

A	B
128. Measure current	A. Ohmmeter
129. Measures voltage	B. Ammeter
130. Measures resistance	C. Voltmeter
131. Measures current, voltage resistance	D. Tape meter
	E. Multimeter

Answers

128.B	129.C	130.A	131.E
-------	-------	-------	-------

9.11 Electric Safety

We humans are good conductors of electricity and electric shock can result in fatal burns and causes the heart to malfunction.

In fact, the degree of damage to the body depends on the magnitude of the current and the time of exposure.

For example, current of 5mA or less can cause a sense of shock with no damage and a current of 10mA cause muscle to contract.
A current of 100mA and larger can be fatal.

What is more, the current that passes through a 60W bulb is about 0.5A and this current entering our body could be deadly.

We need to protect our selves and our electric devices from over dose of current. To protect devices from damaging against short circuits and overloading of circuits we use fuse.

Fuse: Is a metal of low melting point inserted in a circuit as a protective device



Fuse

132. How will a fuse provide protection against excessive current during short circuits?

Explanation:

When the current is beyond the safe limit, the fuse melts and disconnects the current flow and keep the device safe from damaging.

End of Unit Questions and Problems

I. Give short Answer to the following Questions.

- What are the types of charges exist in nature?
- State the fundamental law of electrostatics
- What is charging?
- What are the mechanisms of charging a body?
- State the law of conservation of charge
- What is an electroscope?
- What is a lightning rod?
- State coulomb's law
- What is electric field strength?
- Describe the characteristics of electric field lines
- What is an electric current?

12. State ohm's law

13. Describe the factors that affect resistance of metallic wire

14. What is a multimeter?

15. List electric safety rules

16. Why isn't a bird sitting on a high-voltage power line electrocuted?

17. How will the current change when the voltage is doubled keeping the resistance constant?

18. If aluminium and copper wires of the same length have similar resistances, which one will have larger diameter?

19. Why is the series combination not used for domestic circuits?

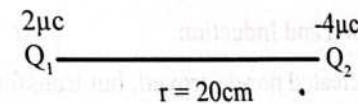
20. Why do we use copper and aluminium wires for electricity transmission?

21. What determines the severity of an electric shock?

22. If all the light in the room go out when an electric heater is plugged. Explain what must have happened?

II. Solve the following Problems

23. Determine the magnitude and direction of the electrostatic force that one charge exerts on the other .



24. Two spheres that are 4cm apart attract each other with a force of $1.2 \times 10^9 \text{ N}$. What is the magnitude of the charge on each sphere if one has twice the charge than the other?

25. If the electrostatics force between two identical charged bodies of each charges $1.1 \times 10^7 \text{ C}$ is $4.2 \times 10^4 \text{ N}$, what is their separation?

26. A copper wire of resistivity $1.6 \times 10^{-8} \Omega \text{ m}$ and 0.5mm diameter has a resistance of 10Ω . What its length?

27. Plot the graph and calculate the resistance of a metallic wire whose current and voltages are following

V (v)	1.5	3	4.5	6	7.5
I (A)	0.1	0.2	0.3	0.4	0.5

28. What resistor should be connected to a 12v battery to produce a current of 2.5mA in the circuit?
29. If a battery of 9v is connected in series with 2Ω , 3Ω , 4Ω , 5Ω and 12Ω resistors, then what current flows through the 5Ω resistor?
30. How many 176Ω resistors should be connected in parallel to get a 5A current on a 220v line?
31. How should three resistors of each 6Ω resistance be connected so that their combination has a resistance of
- A. 9A
B. 4Ω
32. Why is it dangerous to use a fuse that is rated 30A on a circuit calling for a 15A fuse?

I. Answers to the End of Unit Questions

- There are two types of charges, Negative and Positive.
- Like charge repel each other and unlike charges attract each other.
- Charging is the process of transferring charge from one body to the other.
- Rubbing, conduction and Induction.
- Charge is neither created nor destroyed, but transferred from one body to the other
- Electroscope is a device used to detect charge
- Lighting rod is a metallic rod mounted at the top of a building to keep the structure safe from lightning.
- Coulomb's law state that, the electrostatic force between two point charges is directly proportional to the product of their charges and inversely proportional to the squire of their separation.
- Electric field strength is the electric force per unit charge acting on a test charge placed in the vicinity.
- Field lines are:-Symmetrical
 - Never cross - each other
 - Perpendicular to the charged body

- Closer where the field is stronger
 - Run from positive to negative charge
- Electric circuit is a closed path for the flow of electric current.
 - Ohm's law states that, current flowing in a circuit increases as the voltage across the ends of the conductor increases.
 - Length, cross-sectional area, temperature and the material from which the wire is made are some of the factors that affect resistance of a metallic conductor
 - Multimeter is a device that is used to measure the current, resistance and voltage in a circuit
 - Use fuse, use grounding, use insulators, handles, switch off power while working on a live wire.
 - Its leg is insulator and the circuit is open as long as the bird sit on a single wire

$$17. I_1 = \frac{V_1}{R}$$

$$I_2 = \frac{V_2}{R}, V_2 = 2V_1$$

$$I_2 = \frac{2V_1}{R} = 2\left(\frac{V_1}{R}\right)$$

$$I_2 = 2I_1, \text{ doubled}$$

$$18. R = \frac{\rho \ell}{A} = 4 \frac{\rho \ell}{\pi d^2}$$

$$R_{Al} = \frac{4\rho_{Al}\ell}{\pi d_{Al}^2} \text{ and } R_{cu} = \frac{4\rho_{cu}\ell}{\pi d_{cu}^2}, R_{Al} = R_{cu}$$

$$\frac{R_{Al}}{R_{cu}} = \frac{d_{cu}^2 \rho_{Al}}{d_{Al}^2 \rho_{cu}} = 1$$

$$\frac{d_{Al}^2}{d_{cu}^2} = \frac{\rho_{Al}}{\rho_{cu}}, \text{ But } \rho_{Al} > \rho_{cu}$$

Therefore, Aluminium has larger diameter

19. This is so because, in series connection, if the line fails at some point, all the electric devices stop working.
20. Because, they have very small resistance as compared to other available conductors.
21. It depends on the magnitude of the current, the length of time of exposure and the part of the body involved.
22. Because, electricity transfers from the outlet into the bulbs and causes a rapid draw on.

II. Solution to the end of Unit Problems

$$23. F = \frac{kQ_1Q_2}{r^2} = \frac{(9 \times 10^9)(2 \times 10^{-6})(4 \times 10^{-6})}{(20 \times 10^{-2})^2}$$

$$F = 6 \times 10^{-4} \text{ N, Attractive}$$

$$24. F = \frac{kQ_1Q_2}{r^2}, Q_2 = 2Q_1$$

$$F = \frac{2kQ_1^2}{r^2} = Q_1^2 = \frac{Fr^2}{2k}$$

$$Q_1 = \sqrt{\frac{Fr^2}{2k}} = \sqrt{\frac{(1.2 \times 10^9)(4 \times 10^{-2})^2}{2(9 \times 10^9)}}$$

$$Q_1 = 1 \times 10^{-11} \text{ C and } Q_2 = 2Q_1 = 2 \times 10^{-11} \text{ C}$$

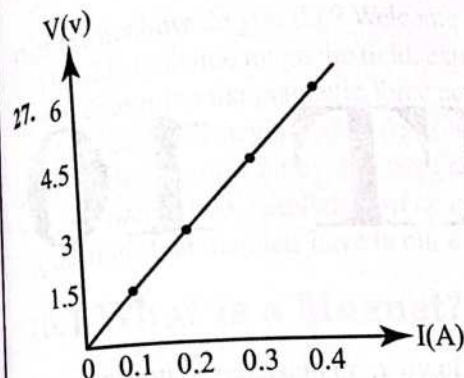
$$25. F = \frac{kQ_1Q_2}{r^2} = \frac{kQ^2}{r^2}$$

$$r^2 = \frac{kQ^2}{F}$$

$$r = \sqrt{\frac{kQ}{F}} = (1.1 \times 10^7) \sqrt{\frac{9 \times 10^9}{4.2 \times 10^4}} = 0.5 \text{ m}$$

$$26. R = \rho \frac{\ell}{A} = \frac{4\rho\ell}{\pi d^2}$$

$$\ell = \frac{R\pi d^2}{4\rho} = \frac{(10)(3.14)(0.5 \times 10^{-3})^2}{4(1.6 \times 10^{-8})} = 123 \text{ m}$$



$$R = \frac{V}{I} = \frac{7.5 - 1.5}{0.5 - 0.1} = \frac{6}{0.4} = 15 \Omega$$

$$28. V = IR$$

$$R = \frac{V}{I} = \frac{12}{2.5 \times 10^{-3}} = 4.8 \times 10^3 \Omega$$

$$29. V = IR$$

$$I = \frac{V}{R} = \frac{12}{2+3+4+5+12} = 0.5 \text{ A}$$

$$30. R_T = \frac{V}{I} = \frac{220}{5} = 44 \Omega$$

$$\frac{1}{R_T} = \frac{n}{176}$$

$$n = \frac{176}{44} = 4 \text{ Resistors}$$

UNIT 10

10. Magnetism

- 10.1 What is a Magnet ?
- 10.2 Magnetic Field
- 10.3 Earth's Magnetic Field
- 10.4 Magnetic Force on a Moving Charge
- 10.5 Magnetic Force on a Current Carrying Wire
- 10.6 Magnetic Field Current Carrying Wire
- 10.7 Magnetic Force Between two Parallel Current Carrying Wires

10. Magnetism

Dear learner, how do you do ? Welcome to this impressive unit where you will be able to define magnetic field, explore the cause of Earth's magnetic nature, determine the magnetic force acting on a moving charged particle and on a current carrying wire, describe the nature and magnitude of the magnetic field produced by a current carrying wire, find out the magnetic force between two parallel current carrying wires and appreciate the applications that magnets have in our every day life.

10.1 What is a Magnet?

The attraction or repulsion property of some materials due to the spinning of their electrons is called magnetic effect.

Materials such as Nickel, cobalt and steel are said to be magnetic. And, the natural occurring stone with magnetic property is called *lodestone*.

Types of Magnets

Magnets are categorized as permanent, temporary and electromagnet.

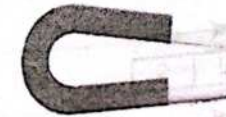
i. Permanent Magnet

Is made from specialized iron ores, steel ... etc. and have a prolonged magnetic property.

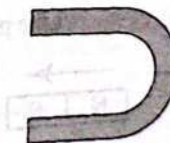
Permanent magnets are available in different shapes and sizes as shown below.



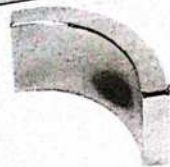
Bar magnet



Horse shoe magnet



U shape magnet



Arc magnet



Ring magnet



Cylindrical magnet

Permanent magnets can demagnetized or lose their magnetic property if they are over heated, hammered or stroked.

ii. Temporary Magnets

Soft irons such as nail and paper - clip gain magnetic property when immersed in an external magnetic field and lose their magnetic property when the magnetic field is removed.

iii. Electromagnet

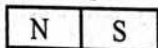
Is a coil of wire with an iron core inside of it and acts as a magnet when current passes through it.

These magnets are used in generators, motors and transformers

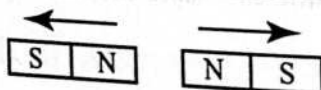
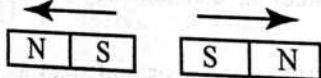
Properties of Magnets

The basic properties of magnets are

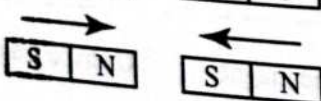
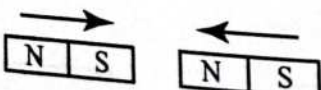
- Every Magnet has two poles. North and south



- Like poles repel each other and unlike poles attract each other

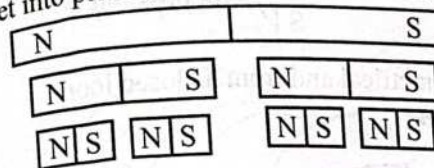


Like poles repel



unlike poles attract

Magnetic poles exist in pairs. There is no isolated single pole. If you cut a magnet into pieces, each piece will have both north and south poles.



10.2 Magnetic Field

Magnetic field is produced by a magnet and a current carrying conductor

Magnetic field : Is a region around a magnet and a current carrying conductor where a magnetic force is felt.

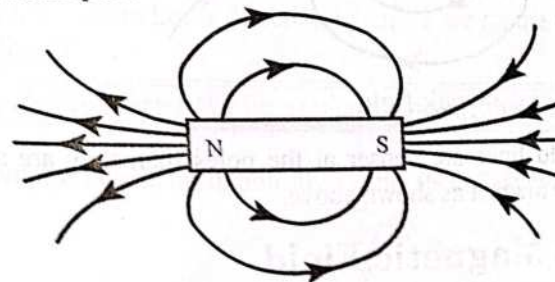
The direction and intensity of a magnetic field is visualized using imaginary lines called *magnetic field lines*.

- The direction of a magnetic field is determined using the deflection direction of a compass needle placed near the magnet.

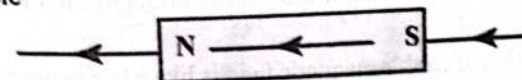
Characteristics of Magnetic Field Lines

Some of the properties of magnetic field lines are the following.

- Outside the magnet, magnetic field lines run from the North pole to the South pole.



- Inside the magnet, magnetic field lines run from the south pole to the North pole

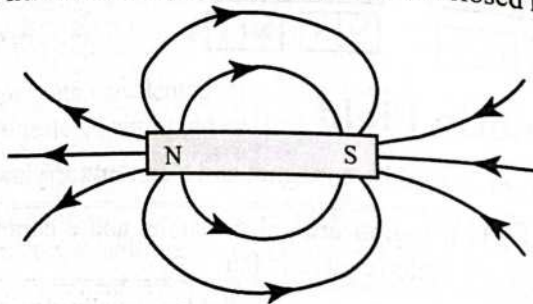


- Magnetic field lines never cross each other

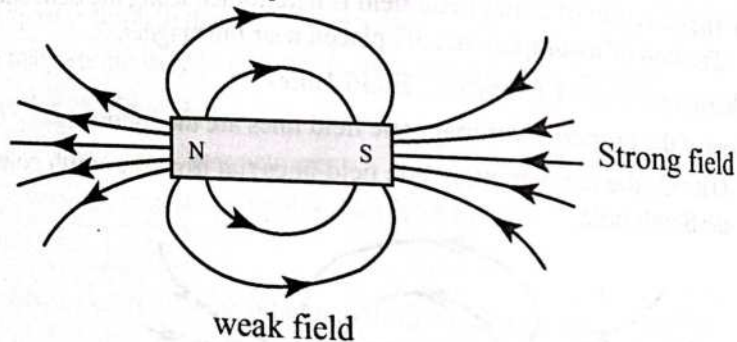


Not possible

- Magnetic field lines are symmetrical and form a closed loop.



- Magnetic force is stronger where the field lines are closer together and weaker where they are far apart

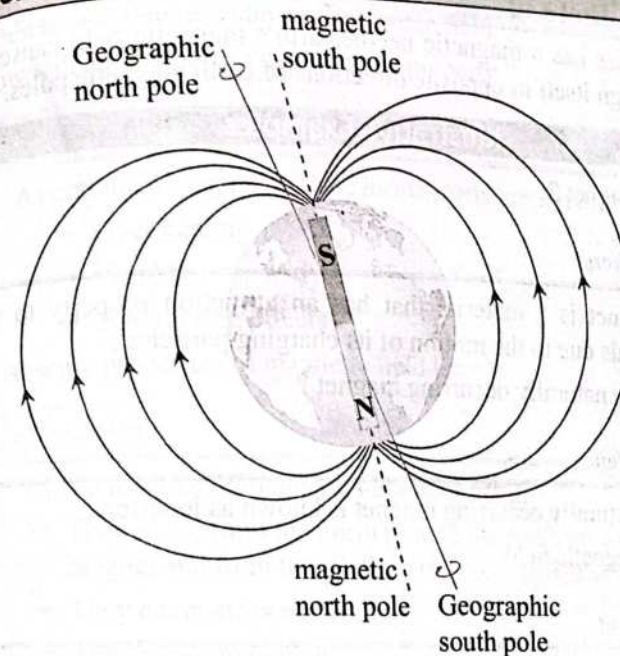


- Magnetic field lines are denser at the poles than they are at the middle of the magnet as shown above.

10.3 Earth's Magnetic Field

The earth acts as a huge bar magnet and the cause of earth's magnetic field is thought to be the circulation of molten materials in the outer core layer of the earth.

- The orientation of earth's magnetic field is like a bar magnet tilted about 11° from the geographic North pole as shown below



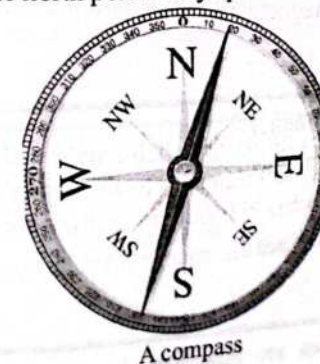
- Earth's magnetic South pole is near the geographic north pole and the earth's magnetic North pole is near the geographic south pole

A) Compass

Compass is used to know direction when we are on the land, on the ocean and in the air

Compass : Is a material with a magnetic needle that is free to rotate.

The compass needle north pole always points in the geographic North pole



A compass

Since Compass has a magnetic needle, earth's magnetic field causes it to rotate and align itself in opposite directions of earth magnetic poles.

Illustrative Examples

1. What a Magnet ?

Explanation

A magnet is a material that has an attraction property to some materials due to the motion of its charging particles.

2. What is the naturally occurring magnet ?

Explanation

The naturally occurring magnet is known as lodestone

3. What is magnetic field

Explanation

Magnetic field is a region around a magnet or a current wire where magnetic force is felt

4. What are the properties of magnets ?

Explanation

- Magnets have north and south poles
- Magnetic poles always exist in pairs. There is no single pole
- Like poles repel and unlike poles attract each other

5. What are the types of magnets ?

Explanation

Permanent magnet
Temporary magnet
Electromagnet

6. What are magnetic field lines ?

Explanation

Magnetic field lines are imaginary lines used to visualize the

direction and magnitude of magnetic field.

7. How will a magnet lose its magnetic property ?

Explanation

A permanent magnet can lose its magnetic property if it experiences ;

- Over heating
- Stroking
- Hammering effects

8. List some properties of magnetic field lines ?

Explanation

Characteristics of magnetic field lines are

- They move from the north pole to the south pole outside the magnet and from the south to the north pole inside the magnet
- They never cross each other
- They are symmetrical
- They form closed loop
- The field is stronger where the field lines are closer

9. State the fundamental law of magnetism

Explanation

The basic law of magnetism states that ;

Like poles repel each other and unlike poles attract each other.

10. What is the evidence that supports the idea that earth has a magnetic field ?

Explanation

One possible evidence that supports the existence of earth's magnetic field is the alignment of a compass or a bar magnet in the North - South direction when suspended in air

11. What is the cause of earth's magnetic field ?

Explanation

The cause of earth's magnetic field is assumed to be the circulation of molten materials inside the earth.

12. What is a compass ?

Explanation

A compass is a magnetic needle that is free to rotate and shows us direction.

13. Why does the needle of a compass point in the North - South direction ?

Explanation

Because, the earth's magnetic field interacts with the magnet of the compass and the alignment is based on the fundamental law of magnetism.

14. Is there any difference between the geographic and magnetic poles of the earth ?

Explanation

Yes. The earth's magnetic south pole is near the geographic North pole and the earth's magnetic north pole is near the geographic south pole

15. What is the angle of inclination of the earth's magnetic south pole from the geographic north pole ?

Explanation

The earth's magnetic south pole is tilted about 11° towards west from the geographic north pole.

16. Can we expect a huge solid bar magnet in side the earth ?

Explanation

No. The inner layer of the earth, the core is of extreme temperature and hence, materials exist in a molten state. Therefore, a solid huge bar magnet could not exist in the interior of the earth.

10.4 Magnetic Force on a Moving Charge

When a moving charge is subjected to a uniform external magnetic field, it experiences a force. And, the magnitude of the magnetic force acting on a charged particle moving in a uniform magnetic field is obtained by;

$$F = QvB \sin \theta$$

Where: F = magnetic force on the particle

v = Speed of the particle

Q = charge of the particle

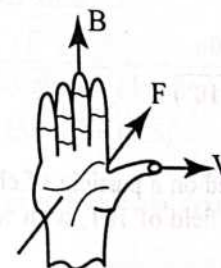
B = magnetic field strength

θ = Angle between direction of motion of the particle and the magnetic field

Magnetic field strength, B is a vector quantity and its SI unit is the Tesla (T). Moreover, the direction of the force acting on the moving charged particle is determined using the right hand rule.

Right Hand Rule : If you point your right hand thumb in the velocity direction and your other fingers in the field direction, then your palm will point in the force direction.

For example, if the particle is moving to the right in a field directed away from you, then the force on the particle will be up ward as shown in the figure.



Conceptual Examples

17. Will the magnetic force on a moving charge be zero in a non - zero field ?

Explanation

Yes. The force on a moving charged particle immersed in a uniform magnetic field is zero when the particle is moving parallel or anti

parallel to the field.

18. When will the magnetic force acting on a charged particle become maximum?

Explanation

When the particle moves perpendicular to the direction of the magnetic field.

Illustrative Examples

19. What is the magnetic force acting on a particle of charge 2 nC moving at a speed of $6 \times 10^5 \text{ m/s}$ at an angle of 30° to a uniform magnetic field of 100 T ?

Solution:

$$F = QvB \sin\theta$$

$$F = (2 \times 10^{-6})(6 \times 10^5)(100) \sin(30^\circ), \sin 30^\circ = 0.5$$

$$F = 12 \times 10 \times 0.5 = 60 \text{ N}$$

20. A magnetic force of 100 N is acting on a 5 nC charge moving at a speed of $8 \times 10^6 \text{ m/s}$ at right angle to a uniform magnetic field. What is the magnetic field strength?

Solution:

$$F = QvB \sin\theta, \theta = 90^\circ \text{ and } \sin 90^\circ = 1$$

$$F = QvB$$

$$B = \frac{F}{Qv} = \frac{100}{(5 \times 10^{-6})(8 \times 10^6)} \\ = 2.5 \text{ T}$$

21. If a magnetic force of 80 N acted on a particle of charge 2 nC moving at an angle of 53° to a uniform field of 10 T , with what speed was the particle entered the field?

Solution:

$$F = QvB \sin\theta$$

$$v = \frac{F}{QB \sin\theta}$$

$$v = \frac{80}{(2 \times 10^{-6})(10) \sin 53^\circ}, \sin 53^\circ = 0.8$$

$$v = \frac{80}{(2 \times 10^{-6})(10)(0.8)} \\ = 5 \times 10^4 \text{ m/s}$$

22. If a particle of charge 3 nC moving at a speed of $2 \times 10^6 \text{ m/s}$ along the positive x axis enters a uniform field of 50 T directed in the positive y axis, what is the magnitude and direction of the force acting on the particle?

Solution:

$$\vec{F} = Q(\vec{v} \times \vec{B})$$

$$F = QvB \sin\theta, \theta = 90^\circ \text{ and } \sin 90^\circ = 1$$

$$F = (3 \times 10^{-6})(2 \times 10^6)(50)$$

$$F = 300 \text{ N, along the positive } z \text{ axis}$$

23. What is the charge carried by a particle that is moving at a speed of $4 \times 10^5 \text{ m/s}$ in a uniform field of 10 T at an angle of 37° and experienced a force of 60 N ?

Solution:

$$F = QvB \sin\theta$$

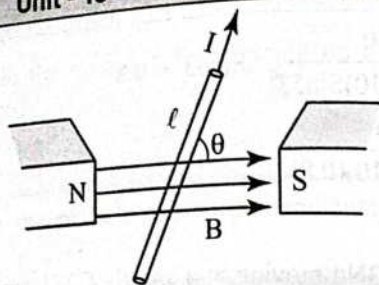
$$Q = \frac{F}{vB \sin\theta} = \frac{60}{(4 \times 10^5)(10)(0.6)}$$

$$Q = 0.25 \times 10^{-6} = 0.25 \mu\text{C}$$

10.5 Magnetic Force on a Current Carrying Wire

A current carrying wire feels magnetic force when subjected to a magnetic field since the wire is full of many moving particles.

The magnitude of the magnetic force acting on a current wire exposed to a magnetic field is obtained as follows:



$$F = I \ell B \sin \theta$$

Where : F = Magnetic force acting on the wire

I = Current flowing through the wire

ℓ = Length of the wire

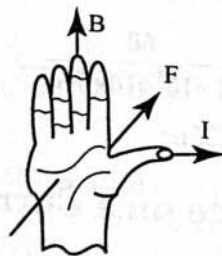
B = Magnetic field strength

θ = Angle between the length element and field

Moreover, the direction of the force acting on the wire is determined using the right hand rule

Right Hand Rule : If you point your right hand thumb in the current direction and your other fingers in the field direction, then your palm faces in the magnetic force direction .

For example, if current is moving to the right and the magnetic field is away from you, then the force on the wire will be upward - out of the page.



Illustrative Example

24. When will the magnetic force on a current wire become zero ?

Explanation

When the current flows parallel or anti - parallel to the field, the

force on the wire is zero.

25. When will the magnetic force on a current carrying wire become maximum ?

Explanation

When the wire is perpendicular to the external magnetic field.

26. What is the magnitude of the force on a wire that carried a current of 5A and whose 25cm length element is immersed in a magnetic field of 0.8T at an angle of 37° ?

Solution:

$$F = I \ell B \sin \theta \quad \sin 37^\circ = 0.6$$

$$F = (5)(0.25)(0.8)(0.6) \\ = 0.6\text{N}$$

27. What is the force per length acting on a wire that carried a current of 5A subjected to a magnetic field of 0.8T perpendicularly ?

Solution :

$$F = I \ell B \sin \theta, \quad \sin 90^\circ = 1$$

$$F = I \ell B$$

$$\frac{F}{\ell} = I B = (5)(0.8) \\ = 4 \text{ N/m}$$

28. What current is flowing through a wire of 50cm if it experienced a force of 20N when subjected to a magnetic field of 20T at an angle of 30° ?

Solution:

$$F = I \ell B \sin \theta$$

$$I = \frac{F}{\ell B \sin \theta}, \quad 30^\circ = 0.5$$

$$I = \frac{20}{(0.5)(20)(0.5)} \\ = 4\text{A}$$

29. What is the magnitude and direction of a magnetic field in to which a

wire of length 50cm carrying current of 2A along the positive x axis experiences a 10N magnetic force along the positive y axis ?

Solution:

$$\vec{F} = I(\vec{\ell} \times \vec{B})$$

$$F = I \ell B \sin \theta, \quad \theta = 90^\circ$$

$$F = I \ell B$$

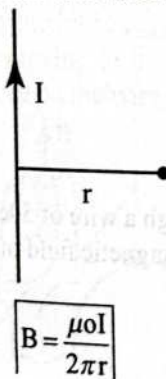
$$B = \frac{F}{I \ell} = B = \frac{10}{(2)(0.5)} = \frac{10}{1}$$

$$B = 10\text{T along the negative z axis}$$

10.6 Magnetic Field of a Current Carrying Wire

A current carrying conductor produces magnetic field around it, and a magnet produces electric current.

The magnitude of the magnetic field produced due to a current carrying wire at some distance from the wire is obtained by;



Where: $\mu_0 = 4\pi \times 10^{-7} \frac{\text{Tm}}{\text{A}}$ is called *permeability of free space*

I = current flowing through the wire

r = distance from the wire

Moreover, the direction of the magnetic field of a current carrying wire is determined using the right hand rule.

Right Hand Rule : If you grasp the current carrying wire with your right hand in such a way that your thumb points in the current direction, then your other fingers will curl in the direction of the magnetic field.

Symbols used to indicate field and current direction;

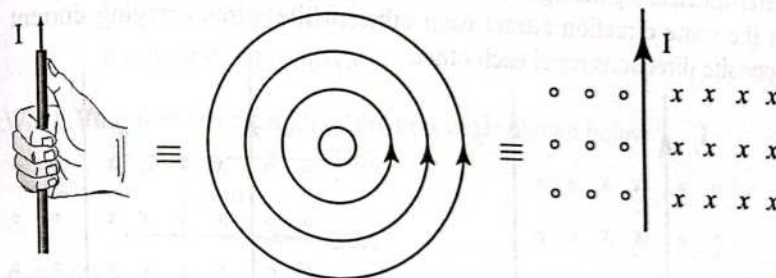
$\times$ = Magnetic field directed into the page

$\cdot$ = Magnetic field directed out of the page

$\otimes$ = Electric current directed into the page

$\odot$ = Electric current directed out of the page

For example, if current is flowing up ward, through a wire, then the magnetic field is counter clockwise according to the right hand rule.



Illustrative Examples

30. What is the magnitude and direction of the magnetic field at 4cm from a wire of current 5A flowing downward ?

Solution :

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B = \frac{(4\pi \times 10^{-7})(5)}{2\pi(0.04)}$$

$$= 0.25 \times 10^{-4} \text{ T, Clockwise.}$$

31. At What distance from a wire of current 2A will the magnetic field strength be 0.5T

Solution:

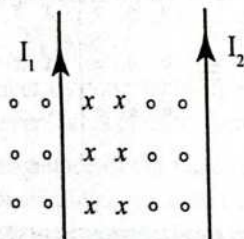
$$B = \frac{\mu_0 I}{2\pi r}$$

$$r = \frac{\mu_0 I}{2\pi B} = \frac{(4\pi \times 10^{-7})(2)}{2\pi(0.5)}$$

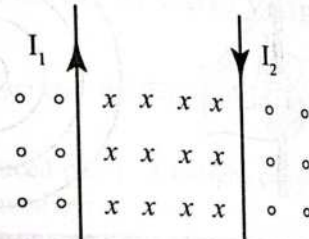
$$r = 8 \times 10^{-7} \text{ m}$$

10.7 Magnetic Force between two Parallel Current Carrying wires

The nature of the magnetic force between two current carrying wires is determined using the right hand rule. As a result, two wires carrying current in the same direction attract each other, while wires carrying current in opposite directions repel each other.

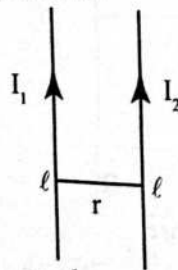


Attract each other



Repel each other

And, the magnitude of the magnetic force between two straight parallel wires is obtained as follows :



$$F = \frac{\mu_0 I_1 I_2 \ell}{2\pi r}$$

Where : I_1 = current flowing through wire - 1

I_2 = current flowing through wire - 2

ℓ = length of the wires

r = separation of the wires.

Illustrative Examples

32. What is the magnetic force between two wires of each 100m long, 5cm apart and carrying currents of 15A and 30A in opposite directions ?

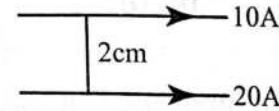
Solution :

$$F = \frac{\mu_0 I_1 I_2 \ell}{2\pi r}$$

$$F = \frac{(4\pi \times 10^{-7})(15)(30)(100)}{2\pi(5 \times 10^{-2})}$$

$$F = 0.18 \text{ N, Repulsive}$$

33. What is the force per length of the two wires shown below ?



Solution :

$$F = \frac{\mu_0 I_1 I_2 \ell}{2\pi r}$$

$$\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

$$\frac{F}{\ell} = \frac{(4\pi \times 10^{-7})(10)(10)}{2\pi(2 \times 10^{-2})}$$

$$= 10^{-3} \text{ N/m, Attractive}$$

34. Two parallel wires that are 10cm apart carry same currents and interact with a force of 0.08N/m. What is the current in each wire

Solution :

$$\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi r} = \frac{(4\pi \times 10^{-7})(I)(I)}{2\pi(0.1)} = 2 \times 10^{-6} I^2$$

$$0.08 = 2 \times 10^{-6} I^2$$

$$I = 200A$$

35. Magnetic domains are :

- A) The magnetic poles of a bar magnet
- B) Microscopic magnets in the magnet
- C) Collection of similar magnetic poles
- D) Bar magnets arranged in the same direction

Hint: Magnetic domains are tiny magnets

36. The Magnetic field is into the page If a proton is moving in the field at velocity v , the magnetic force on the proton is directed :

A. ←

B. →

C. ↑

D. ↓

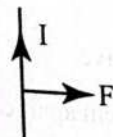
x x x x
x x x x
⊕ → v
x x x x

Hint: use the right hand rule.

37. The direction of the magnetic force on a current carrying wire is shown. What is the direction of the magnetic field ?

- A) Into the plane of this page
- B) In the direction of the force
- C) In the direction of the current
- D) Out of the plane of this page

Hint: use the right hand rule



38. A charged particle moving perpendicularly to magnetic field may experience a path with constant.

- A) Velocity
- B) Acceleration
- C) Radius
- D) Displacement

Hint: The charged particle will follow a circular path of constant radius.

Answer : B

39. An electron moving due east in a uniform magnetic field directed into the page may experience a force towards

- A) North
- B) South
- C) East
- D) West

Hint: Use right hand rule and then reverse direction so, in this case North is a proton, south for an electron

Answer : B

40. For what orientation between the moving charge particle and the uniform magnetic field will the force become maximum ?

- A) $\theta = 0^\circ$
- B) $\theta = 45^\circ$
- C) $\theta = 90^\circ$
- D) $\theta = 180^\circ$

Hint: $F = QvB \sin \theta$, $\sin(90^\circ) = 1$

$F = QvB$, maximum

Answer : C

41. What is the magnetic field strength 10cm from a straight wire of current 3A ?

- A) 3T
- B) 10T
- C) $6 \times 10^{-6}T$
- D) $6 \times 10^{-7}T$

Solution:

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7})(3)}{2\pi(0.1)}$$

$$B = 6 \times 10^{-6} T$$

Answer : C

42. A current wire is put in a uniform magnetic field All the modifications will change the magnitude the magnetic force. Except

- A) Doubling the current through the wire
- B) Increasing the magnetic field strength
- C) Rotating the wire to change its orientation
- D) Reversing the direction of flow of the current

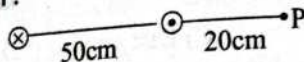
Hint: $F = ILB \sin \theta$

Answer : D

43. Two long parallel conductors that are 50cm apart carry currents $I_1 = 7A$ and $I_2 = 10A$ in opposite directions. What is the resultant magnetic field at point P ?

- A) $8 \times 10^{-6}T$ up
- B) $8 \times 10^{-6}T$ down
- C) $1.2 \times 10^{-5}T$ up
- D) $1.2 \times 10^{-5}T$ down

Solution :



$$B_p = B_2 - B_1$$

$$B_p = \frac{\mu_0 I_2}{2\pi r_2} - \frac{\mu_0 I_1}{2\pi r_1}$$

$$B_p = \frac{4\pi \times 10^{-7}}{2\pi \times 10^{-2}} \left[\frac{10}{20} - \frac{7}{70} \right]$$

$$= 8 \times 10^{-6} \text{ T up}$$

Answer : A

44. If two long parallel wires 1m apart carry the same current and the force per unit length on each wire is $2 \times 10^{-7} \text{ N/m}$, then what is the current in each wire ?

A) 2A

B) 1A

C) 3A

D) $2 \times 10^{-7} \text{ A}$

Solution :

$$F = \frac{\mu_0 I_1 I_2 \ell}{2\pi r}$$

$$\frac{F}{\ell} = \frac{\mu_0 I^2}{2\pi r}$$

$$2 \times 10^{-7} = \frac{(4\pi \times 10^{-7}) I^2}{2\pi (1)} \times 10^{-7}$$

$$2 = 2I^2 \quad I = 1 \text{ A}$$

Answer : B

45. A positive charge moving upward enters a magnetic field directed to the North. The force on the charge will be towards ?

A) North

B) South

C) East

D) West

Hint: using the right hand rule,

Answer : D

46. A magnetic field ;

A) Always exert a force on a charged particle

B) Never exert a force on a charged particle

C) Exert force on a charged particle moving across it

- D) Exert force on a charged particle moving along it
Hint: $F = qvB \sin\theta$

Answer : C

47. The North pole of Earth's magnet is near the geographic
A) South B) North C) East D) West

Hint: 11° tilted from the south

Answer : A

48. How much current should a wire carry to produce a magnetic field of 0.8 T at distance of 2mm ?

A) $4 \times 10^3 \text{ A}$ B) $2 \times 10^3 \text{ A}$ C) $8 \times 10^3 \text{ A}$ D) $6 \times 10^3 \text{ A}$

Solution :

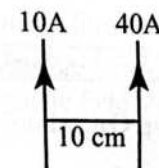
$$B = \frac{\mu_0 I}{2\pi r} \Rightarrow I = \frac{(B)(2\pi r)}{\mu_0}$$

$$I = \frac{(0.8)(2\pi)(2 \times 10^{-3})}{4\pi \times 10^{-7}}$$

$$= 8 \times 10^3 \text{ A}$$

Answer : C

49. What is the magnetic field strength at the mid - point of the two wires

A) $1.2 \times 10^{-6} \text{ T}$ into the pageC) $1.2 \times 10^{-4} \text{ T}$ into the pageB) $1.2 \times 10^{-6} \text{ T}$ out of the pageD) $1.2 \times 10^{-4} \text{ T}$ out of the page

Solution :

$$B = B_2 - B_1$$

$$B = \frac{\mu_0 I_2}{2\pi r_2} - \frac{\mu_0 I_1}{2\pi r_1}, r_1 = r_2 = 5 \times 10^{-2} \text{ m}$$

$$B = \frac{4\pi \times 10^{-7}}{(2\pi (5 \times 10^{-2}))} [40 - 10]$$

$$B = 12 \times 10^{-5} \text{ T} = 1.2 \times 10^{-4} \text{ T, out of the page}$$

Answer : D

50. A permanent magnet

- A) Attract all materials
- B) Attract only magnetic materials
- C) Attract magnetic materials and repel non magnets
- D) Attract non - magnets and repel magnetic materials

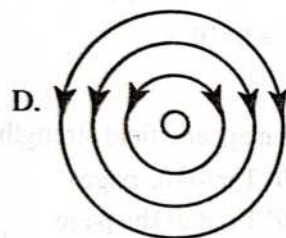
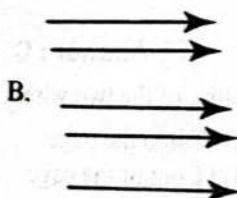
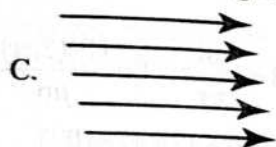
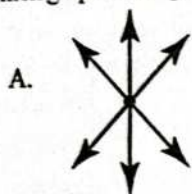
Answer : B

51. Out of the following which one is non - magnetic ?

- A) Zinc
- B) Steel
- C) Copper
- D) Cobalt

Answer : A

52. Which graph of magnetic field lines represent a uniform magnetic field ?



Answer : C

End of unit Questions and problems

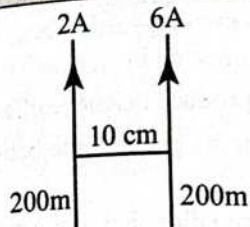
I. Give short Answers to the Following Questions

- How is a magnetic field produced ?
- Can a magnetic monopole exist ?
- What happens when like poles are brought closer together ?
- Plot magnetic field lines around a bar magnet
- How will a compass help us to plot field lines
- How will a compass help us to know direction
- Is there any difference between the earth's magnetic north pole and the geographic north pole ?

- Can we conclude that a moving particle and a current wire always felt magnetic force when immersed in an external magnetic field ?
- Can an electric current produce magnetic effect ?
- What is the nature of the magnetic force between two parallel current carrying wires
- How can we determine the direction of the magnetic field produced by a Current carrying wire ?
- What will happen to the magnetic field strength of a straight wire if the current is doubled ?
- What will happen to the magnetic force between two straight parallel current carrying wires torrents if ;
 - Their separation is doubled
 - Their separation is halved
 - Their currents are halved

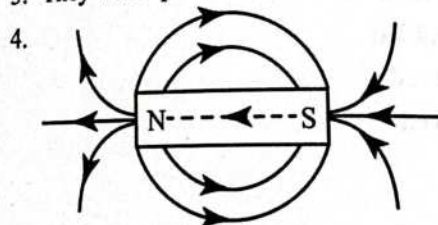
II. End of Unit Problems

- What amount of magnetic force will a 4Nc charge experience when exposed to a field of 0.6 T directed at 45° from the particle's velocity of $4 \times 10^5\text{ m/s}$?
- What perpendicular field to a 50cm wire carrying current of 8A exert a force of 0.4 N ?
- What is the magnetic force on a wire of length 80cm carrying a current of 5A when immersed in a magnetic field of 0.6T perpendicularly ?
- What is the magnetic field strength at a distance of 10cm from a wire of current 25A ?
- Determine the magnetic force acting on an electron that is moving due east at a speed of $8.75 \times 10^5\text{ m/s}$ in a magnetic field of strength 0.75T directed upward
- For the following parallel wires, compute;
 - The force that one wire exerts on the other
 - The force per length



Answers to End of unit Questions

1. It produced due to the spinning of electrons
2. No. Single pole of a magnet does not exist
3. They will repel each other



5. Because the pointer indicates the direction of the field lines
6. Because it is itself a magnet and interacts with earth's magnetic field
7. Yes. The magnetic north pole of the earth is near its geographic south pole
8. No. There orientation with the field matters
9. Yes. it can
10. They attract each other if their current directions are the same. And, repel when they carry currents in opposite directions
11. Using the right hand rule
12. $B_1 = \frac{\mu_0 I_1}{2\pi r}$, if $I_2 = 2I_1$
 $B_2 = \frac{\mu_0 I_2}{2\pi r} = 2B_1$, doubled
- 13.

a) $F = \frac{\mu_0 I_1 I_2}{2\pi r}$ halved

- b.) Doubled
- c) quartered

Solution to End of unit problems

14. $F = QvB \sin \theta$

$$F = (4 \times 10^{-6}) (4 \times 10^5) (0.6) \sin 45^\circ$$

$$F = 0.67 \text{ N}$$

15. $F = I\ell B \Rightarrow B = \frac{F}{I\ell} = \frac{0.4}{(8)(0.5)} = 0.1 \text{ T}$

16. $F = IB\ell = (0.8)(5)(0.6)$

$$F = 2.4 \text{ N}$$

17. $B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7})}{2\pi(0.1)} = 5 \times 10^{-5} \text{ T}$

18. $F = QvB = (1.6 \times 10^{-19})(8.75 \times 10^5)(0.75) = 1.05 \times 10^{-3} \text{ N}$

19. A. $F = \frac{\mu_0 I_1 I_2 \ell}{2\pi r}$

$$F = \frac{(4\pi \times 10^{-7})(2)(6)(200)}{2\pi(0.1)} = 4.8 \times 10^{-3} \text{ N}$$

B. $\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi r} = \frac{(4\pi \times 10^{-7})(2)(6)}{2\pi(0.1)}$

$$\frac{F}{\ell} = 2.4 \times 10^{-6} \text{ N/m}$$

UNIT 11

11. Electromagnetic Wave and Geometrical Optics

- 11.1 What is Electromagnetic Wave
- 11.2 The Electromagnetic Spectrum
- 11.3 Light as a Wave
- 11.4 Laws of Reflection and Refraction
- 11.5 Mirrors and Lenses
- 11.6 The Human Eye and Optical Instruments
- 11.7 Primary Colours of Light and Human Vision
- 11.8 Colour Addition of Light
- 11.9 Colour Subtraction of Light Using Filters

11. Electromagnetic Wave and Geometrical Optics

Welcome to this impressive unit where you will be able to explain the nature and type of electromagnetic waves, describe light wave, state the laws of reflection and refraction of light wave, identify types of mirrors and lenses, find out the nature of images formed by mirrors and lenses, examine the human eye and decide the appropriate lens or mirror to correct eye defects, be familiar with optical devices and engaged in adding and subtraction of colours. Have a nice time.

11.1 What is Electromagnetic Wave

Wave transports energy from one place to another without transferring matter. And, depending on their need of a medium for their production and propagation, waves can be mechanical or electromagnetic.

Mechanical Wave: Is a wave that uses matter to be produced and to move through and can not travel through vacuum.

Examples of mechanical wave include sound wave, water wave and waves on a string.

Electromagnetic Wave: Is a wave produced when an accelerating charged particle enters a region where electric and magnetic field interact and can pass through a medium and a vacuum.

Examples of electromagnetic waves include, light wave, microwave, infrared, ultraviolet, x-ray, Gamma ray.

Did you Know ?

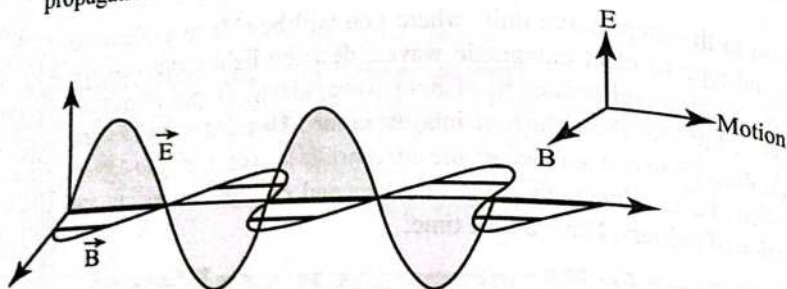
The sun emits radiant energy in the form of electromagnetic wave. And about 92% of this energy is carried by infrared which makes us feel warm. A small amount of the radiant energy is carried by ultra violet, UV light that has the power to cause sunburn, bone cancer and blindness if exposed to it for too long.

Conceptual Example

1. Describe an electromagnetic wave

Explanation : Electromagnetic wave is a transverse wave produced by an accelerating charge in an electric and magnetic fields and can travel in vacuum at a speed of $C = 3 \times 10^8$ m/s.

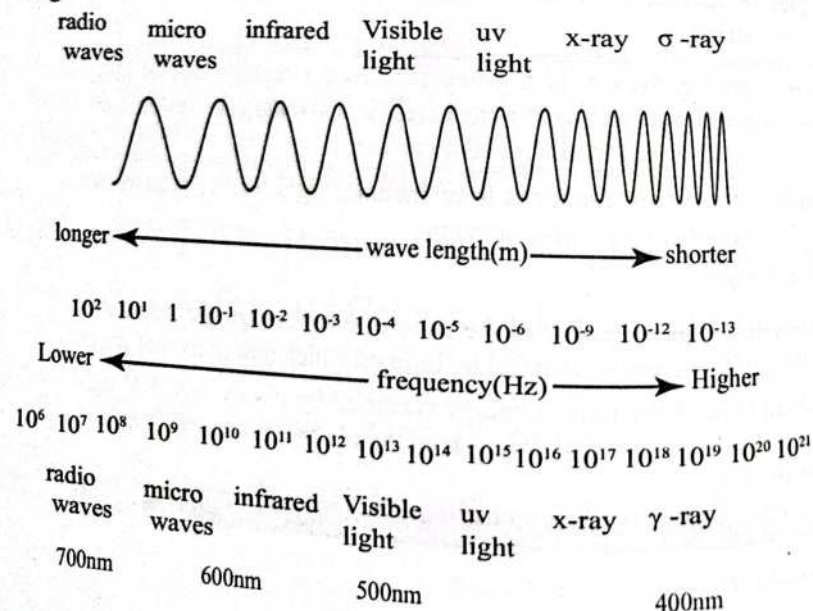
- Plot the nature of the electric and magnetic fields that gives rise to the propagation and production of electromagnetic wave



11.2 The Electromagnetic Spectrum

The electromagnetic spectrum contains a range of frequency and wave lengths. The spectrum consists of radio wave, micro wave, infrared, visible light, ultraviolet, x-ray and gamma ray

The radiations frequency and wavelength in the spectrum has the following range



- ☒ Gamma, γ ray has highest frequency, shortest wavelength and the most penetrating power. And, radio wave has the longest wavelength, shortest frequency and the least penetrating power.

Now, let us study components of the electromagnetic wave one by one.

Radio Wave

They are emitted from transmitters, stars, sparks and lightning.

They have longest wavelength ranging from 1m to thousands of meters and lowest frequency ranging from 500k Hz to 1000MHz.

They are mainly used for communication purposes in police radios, military aircraft radios and television transmissions

- ☒ Over dose of radio wave cause cancer, leukaemia and other disorders

Microwave

They are emitted from electronic devices such as transmitter chip, cell phone, micro oven, antenna and stars. They are used in cell phone, micro oven for cooking, traffic speed central control, for radar air trafficking and for weather forecasting.

- ☒ Over dose of microwave is known to cause, which is a clouding of the cornea.

Infrared Wave

They are given off by hot bodies, stars, lamps, flames and our body. They are used in remote control for TV and video records, in heat lamp to heal in injuries and in cameras to see objects in the dark.

- ☒ Over dose of infrared causes you feel hot.

Visible Light

They are emitted by man made and natural sources of light and create a sense of vision to the eye.

They have a frequency range of 4×10^{14} Hz and 7×10^{14} Hz and a wavelength range of 400nm to 700nm

- ☒ Too much exposure to light ray may damage the retina in the eye.

Ultraviolet UV Light

They are emitted from lamps, the sun and other stars.

They are used to detect bank notes, to harden dental filling, to kill microbes,

to sterilize surgical equipments, foods and to provide vitamin D.

☑ Over dose of UV light may cause sunburn, skin cancer and blindness.

X-rays

They are given off by stars and nebula and they have high frequency and energy

They are used in hospitals to investigate internal part of a body, in airport security checks to examine inside a luggage and in astronomy to examine the space.

☑ Over dose of x-ray can cause cell damage and cancer

Gamma-rays

They are given off by stars and radioactive elements.

They have the highest frequency, the lowest wavelength and the most penetrating power

γ-rays are used in radio therapy to kill cancer cells without physical surgery, to kill microbes, sterilize food and medical equipment

☑ Over dose of γ-ray may cause cancer, mutation in growing tissues.

Illustrative Examples

3. What is the electromagnetic spectrum? Explain

Explanation : Electromagnetic spectrum is a band of radiations with a range of frequencies and wavelengths.

4. List the electromagnetic spectrum in the order of

- A) Increasing wavelength
B) Increasing frequency

Explanation

- A) In the order of increasing wavelength γ-ray, x-ray, UV light, visible light, infrared, Micro wave, Radio wave
B) In the order of increasing frequency Radio wave, Microwave, infrared, visible light, UV light, x-ray and γ-ray

Match the items in column A with those in column B

A

5. Radio wave
6. Micro wave
7. Infrared
8. Visible light
9. Uv light
10. X-ray
11. γ-Ray

B

- A) longest frequency
- B) longest wavelength
- C) 700nm to 400nm
- D) Remote control
- E) Air-port security check
- F) source of vitamin D
- G) Radar control
- H) Require a Medium

Answers

5. B 7. D 9. F 11. A
6. G 8. C 10. E

11.3 Light as a Wave

Light is an electromagnetic wave that can pass through vacuum as well as matter and gives the sensation of vision to the eye.

Speed of light is believed to be the fastest speed in the universe and in vacuum light travels at a speed of 3×10^8 m/s.

And, the wavelength, the speed and frequency of light wave are related by;

$$V = \lambda f$$

Where: V = Speed of light wave

λ = Wavelength of light

f = frequency of light

Note, the equation, $V = \lambda f$ is derived from the

$$\text{fact that } V = \frac{S}{t} = \frac{\lambda}{T}$$

$$V = \lambda \left(\frac{1}{T} \right) = \lambda f. \text{ Ok}$$

Illustrative Examples

12. How long will light take to travel from the sun to the earth which is

about 150 million kilometres ?

Solution :

$$S = Vt \Rightarrow t = \frac{s}{v} = \frac{150,000,000}{3,000,000,000}$$

$$S = 510 \text{ seconds}$$

13. An FM radio Station broad casts at a frequency of 102.1 MHz. What is the wavelength of the radio wave ?

Solution

$$V = \lambda f \Rightarrow \lambda = \frac{V}{f} = \frac{300,000,000}{102100000}$$

$$\lambda = 2.94 \text{ m}$$

14. What is the frequency of a gamma ray of wavelength 10^{-13} m

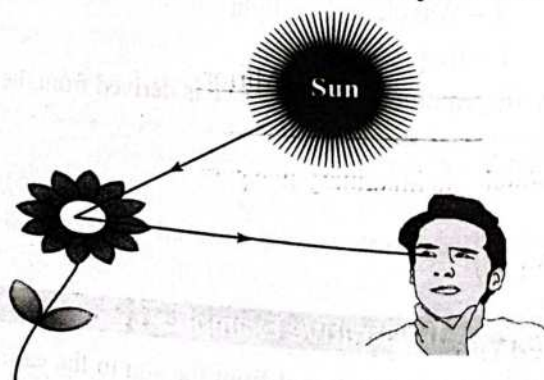
Solution

$$V = \lambda f \Rightarrow f = \frac{V}{\lambda} = \frac{300,000,000}{0.000,000,000,001}$$

$$f = 3 \times 10^{21} \text{ Hz}$$

Did You Know ?

Light travels in a straight line and is represented by using a ray and the group of light rays gives a light beam. What is more, we can see an object when a direct or reflected light come from the object to our eyes.



Therefore, we see an object only when light from the object enters our eyes.

Conceptual Example

15. Give evidence to support the idea that light travels in a straight line

Explanation

The formation of a shadow is one possible evidence to support the idea that light travels in a straight line.

16. Explain how we can see objects ?

Explanation

When light came to our eyes directly or after being reflected from the object.

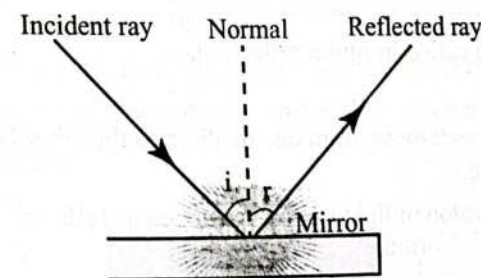
11.4 Laws of Reflection and Refraction

Like all other waves, light undergoes reflection and refraction.

Reflection of Light

It is the bouncing or turning back of light from smooth and polished surfaces such as the mirror, metal sheet or water

Using a ray diagram, we can visualize reflection of light from a mirror as follows.



Where : Normal = Is imaginary line perpendicular to the reflecting surface at the point of incidence.

i = Angle of incidence

r = Angle of reflection

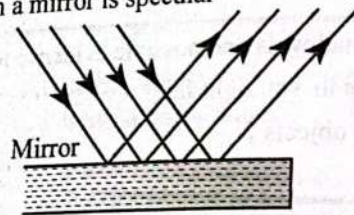
Specular and Diffuse Reflection

Based on the nature of the reflecting surface and the reflected rays,

reflection can be regular or irregular.

Specular Reflection: Is the reflection of light from smooth, polished and shiny surface where the reflected rays move in the same direction parallel to each other.

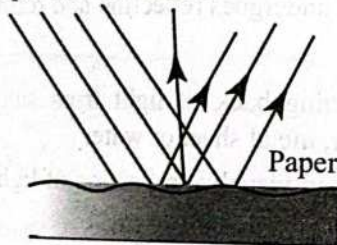
Reflection from a mirror is specular



Specular reflection is also called regular reflection

Diffuse Reflection: Is the reflection of light from rough surface such as paper where the reflected rays move randomly in all directions.

Reflection from a paper sheet is diffuse

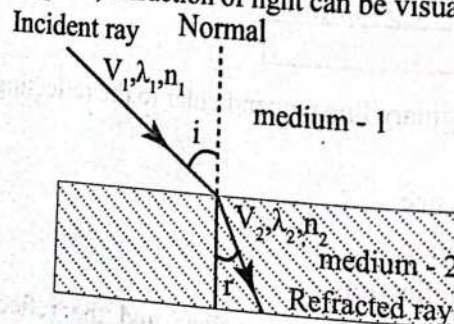


Diffuse reflection is also called irregular reflection.

Refraction of Light

It is the bending of light as it move from one medium to the other because of the change in its speed.

Using ray diagram, refraction of light can be visualized as follows:



Where: n = refractive index

V = Speed of light

λ = Wavelength of light

The Law of Refraction

States that, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant is summarized in Snell's law as follows

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

Refractive index is the measure of how difficult it is for light to get through a material and is defined as

$$\text{Refractive Index} = \frac{\text{speed of light in vacuum}}{\text{speed of light in a material}}$$

$$n = \frac{C}{V}$$

For example, the speed of light in vacuum is 3×10^8 m/s and that in ordinary glass is 2×10^8 m/s, and the refractive index of glass is then ;

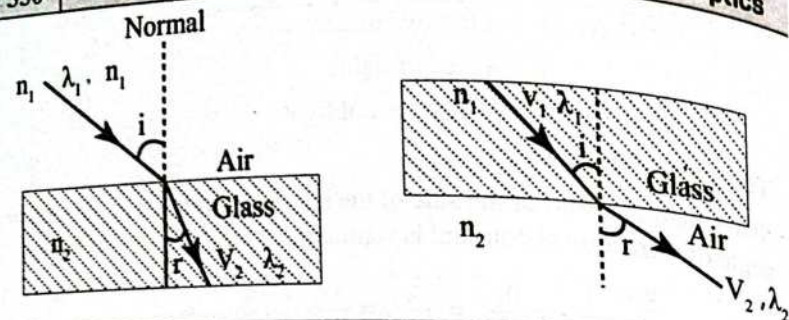
$$n = \frac{c}{v} = \frac{3 \times 10^8}{2 \times 10^8}, \quad n = 1.5$$

☑ Refractive index, n is a dimensionless quantity.

The refractive index of some materials is given below

Material	Refractive Index
Air	1.00
Water	1.33
Glass	1.50
Diamond	2.42

Moreover, when light moves from less dense medium to more dense medium, it bends toward the normal. And, if it moves from more dense medium to less dense medium it bends away from the normal.



Illustrative Examples

17. If light of 600nm wavelength move from air into glass of refractive index 1.5 then what will be its

A) Wavelength, and

B) Speed in glass

Solution

$$\begin{aligned} \text{A) } \frac{n_2}{n_1} &= \frac{\lambda_1}{\lambda_2} \\ \frac{1.5}{1} &= \frac{600}{\lambda_2} \\ \lambda_2 &= 400\text{nm} \end{aligned}$$

$$\begin{aligned} \text{B) } \frac{n_2}{n_1} &= \frac{v_1}{v_2} \\ \frac{1.5}{1} &= \frac{3 \times 10^8}{v_2} \\ v_2 &= 2 \times 10^8 \text{ m/s} \end{aligned}$$

18. A light ray with an angle of incidence 45° is moved from air into water of refractive index 1.3 what will be its

A) Angle of refraction, and

B) Speed in water

Solution

$$\begin{aligned} \text{A) } \frac{n_2}{n_1} &= \frac{\sin i}{\sin r} \\ \frac{1.3}{1} &= \frac{\sin(45^\circ)}{\sin r} = \frac{0.707}{\sin r} \\ \sin r &= \frac{0.707}{1.3} \end{aligned}$$

$$r = \sin^{-1}(0.54)$$

$$r = 34^\circ$$

$$\begin{aligned} \text{B) } \frac{n_2}{n_1} &= \frac{v_1}{v_2} \\ \frac{1.3}{1} &= \frac{3 \times 10^8}{v_2} \\ v_2 &= 2.3 \times 10^8 \text{ m/s} \end{aligned}$$

19. What is the difference between specular and diffuse

Explanation

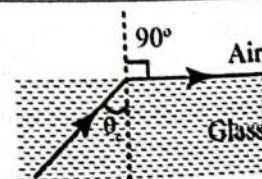
Specular reflection is also called regular reflection is the reflection of light from smooth surface and the reflected rays are parallel to each other. While, diffuse or irregular reflection take place on rough surfaces and the reflected rays move randomly and may cross - each other.

Total Internal Reflection

As its name suggests, total internal reflection involves the returning of light to its initial medium totally. The phenomena of total internal reflection to occur, two conditions must be full filled. These conditions are:

- ☒ Light must move from more dense medium to less dense medium, say from glass to air.
- ☒ The angle of incidence must be greater than the critical angle θ_c .

Critical angle, θ_c : Is the angle of incidence for which the angle of refraction is 90°



Remember, when the angle of incidence is equal to the critical angle, then the refraction is equal to 90° .

Illustrative Examples

20. What is the critical angle for total internal reflection to occur as light moves from glass to air?

Solution:

$$\frac{n}{n} = \frac{\sin i}{\sin i}$$

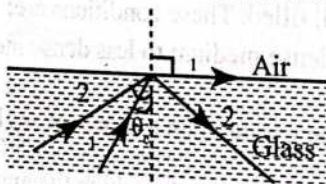
$$\frac{1}{1.5} = \frac{\sin \theta_c}{\sin 90^\circ}, \sin 90^\circ = 1$$

$$\frac{1}{1.5} = \frac{\sin \theta_c}{1}$$

$$\sin \theta_c = \frac{1}{1.5},$$

$$\theta_c = \sin^{-1}(0.67) = 43^\circ$$

Now, when the angle of incidence is greater than the critical angle, total internal reflection occurs as shown below



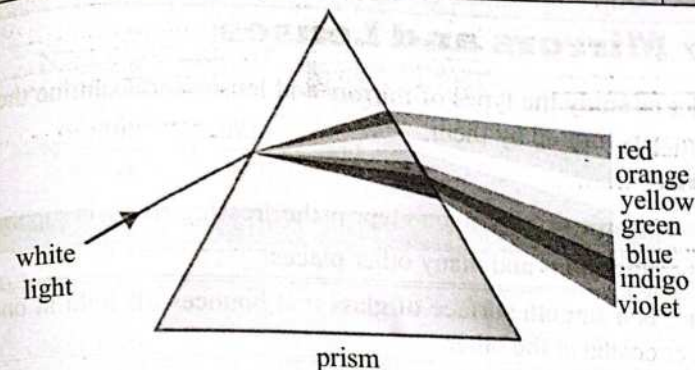
Ray-1 represents the critical angle formation, while ray-2 indicates us the formation of total internal reflection.

Dispersion of Light

White light scatters into different colours up on passing through a prism and this scattering phenomena of light into components is called dispersion.

Dispersion : Is the splitting of white light into its component colours.

For example, when white light passes through a prism, it decomposes into seven different colours as shown below:



The band of colours seen after dispersion is called spectrum of light and is abbreviated as VIBGYOR which stands for violet, Indigo, Blue, Green, Yellow, Orange and Red.

- Red light refracts the least, while violet refracts the most.

Conceptual Examples

21. How is a rainbow formed? Explain

Explanation

It is formed due to refraction of light through droplets

22. What is refractive index? Explain

Explanation:

It is the measure of the quality of the medium to refract light

23. A) Describe total internal reflection B) what is critical angle?

Explanation

- A) Is a condition that occurs when light moves from dense medium and incident angle the greater than the critical angle

- B) It is angle incidence for which $r^\circ = 90^\circ$

24. A) What is dispersion of light? B) Why a diamond sparkles?

Explanation

- A) Dispersion is the scattering of white light into its components as it moves through prism,

- B) It sparkles since it disperses white light into different frequency

11.5 Mirrors and Lenses

Now, let us study the types of mirrors and lenses and examine the nature of the images formed by them.

Mirrors

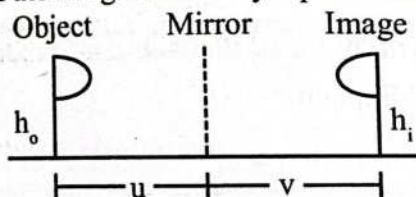
We encounter mirrors of different type in the dressing room, in supermarkets and in beauty salons and many other places.

Mirror : Is a smooth surface of glass that bounces off light at one side but silver coated at the other.

The most common types of mirrors are plane and curved.

Plane Mirror: Is a flat mirror with a reflecting surface at one side but not on the other.

The nature of the image formed by a plane mirror is the following.



The characteristics of the image formed by a flat mirror are

- ☑ Formed behind the mirror
- ☑ Virtual, can not be seen on a screen
- ☑ Same size as the object, $h_i = h_o$
- ☑ Equal distance behind the mirror as the object is in front of the mirror, $u = v$
- ☑ Erect or upright
- ☑ Laterally inverted, right side of the object became left side of the image

Number of Images formed by Two plane mirrors

The number of images formed by two plane mirrors inclined at an angle θ to each other is obtained as follows

$$N = \left(\frac{360^\circ}{\theta} - 1 \right), \text{ if } \frac{360^\circ}{\theta} \text{ is even}$$

$$N = \frac{360^\circ}{\theta}, \text{ if } \frac{360^\circ}{\theta} \text{ is odd}$$

Illustrative Examples

25. What is a mirror ?

Explanation

Mirror is a smooth glass with a reflecting surface at one side and form an image when the reflected light rays intersect

26. What is an image ?

Explanation

Image is the reproduction of an object due to reflection or refraction of light rays.

27. Describe the nature of the image formed by a plane mirror

Explanation

Virtual, erect, laterally inverted, same size as the object, same distance behind the mirror as the object is in front of the mirror.

28. How many images are formed when a body is placed between two plane mirrors that are inclined at an angle of ?

A) 60°

B) 120°

Solution:

$$\text{A) } \theta = 60^\circ$$

$$\frac{360^\circ}{\theta} = \frac{360^\circ}{60} = 6, \text{ even}$$

$$\text{use, } N = \left(\frac{360^\circ}{\theta} - 1 \right)$$

$$N = \left(\frac{360^\circ}{60^\circ} - 1 \right) = (6 - 1) = 5 \text{ images}$$

$$B) \theta = 120^\circ$$

$$\frac{360^\circ}{\theta} = \frac{360^\circ}{120^\circ} = 3, \text{ odd}$$

$$\text{use } N = \frac{360^\circ}{\theta} = \frac{360^\circ}{120^\circ}$$

$$N = 3 \text{ images}$$

29. A pencil of size 10 cm is placed 20 cm in front of a thin plane mirror.

What will be

- A) The size of the image of the pencil
B) The distance from the pencil to its image

Solution

A) Image size = object size = 10 cm

Image of pencil size = 10 cm

B) Image is formed 20 cm behind the mirror,

Therefore, the distance from the pencil to its image is equal to
 $20 + 20 = 40 \text{ cm}$

30. Which one of the following is Not True about the image formed by a plane mirror

- A) diminished B) Same size C) virtual D) same distance

Hint: The image formed by a plane mirror is not diminished or smaller than the object. Rather, it is of the same size as the object.

Answer : A

31. Which one of following is TRUE about the image formed by plane mirror ?

- A) Real C) Inverted
B) Enlarged D) Later Inverted

Hint : The image formed by a plane mirror is not real, diminished, enlarged or inverted

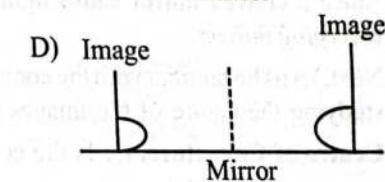
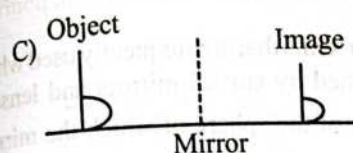
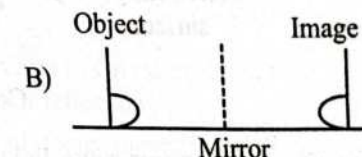
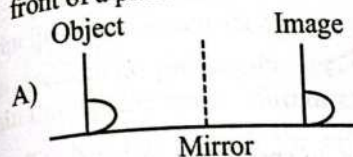
Answer : D

32. The scattering of reflected light rays randomly in all directions from a rough, irregular surface is known as ;

- A) Regular reflection C) Diffuse reflection
B) specular reflection D) mirror Image

Answer : C

33. Which one of the following is the possible image of the body placed in front of a plane mirror



Hint: The correct nature of the image formed by a plane mirror is as in case B.

Answer : B

34. When letter p is placed in front of a plane mirror, its image will be

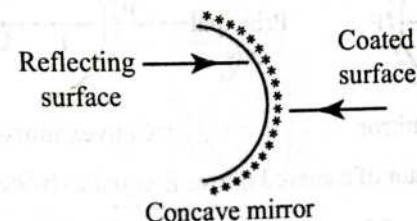
- A) p B) b C) q D) d

Answer: C

Curved Mirrors

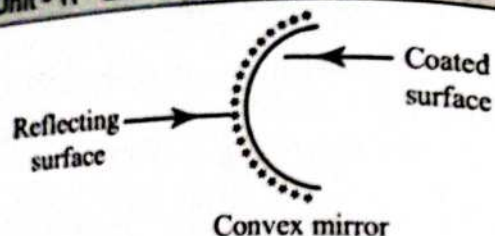
Curved mirrors are also called spherical mirrors and in this section, we are going to study two types of them concave and convex

Concave Mirror: Is formed from the inside surface of a glass sphere and is curved inward like the bowl of a spoon.



Since a concave mirror causes light rays to come together, it is also called a **converging mirror**

Convex Mirror : Is formed from the outer surface of a glass sphere and is curved out ward like the back of a spoon



Since a convex mirror cause light rays to spread out, it is also called a *diverging mirror*

Next, let us be familiar with the common terms that are frequently used when studying the nature of the images formed by curved mirrors and lenses.

Centre of Curvature, C: Is the centre of the sphere of which the mirror is a part.

Radius of Curvature, R: Is the radius of the sphere the mirror made from.

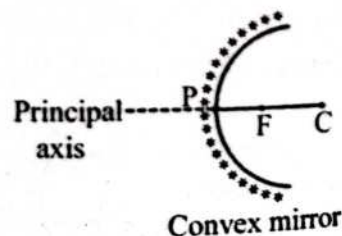
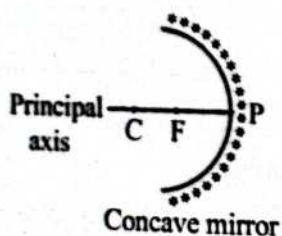
Pole, P: Is the middle point of the curved mirror

Principal Axis: Is the straight line that passes through the centre of curvature and the pole of the mirror

Aperture: Is the periphery or circular out line of the mirror and it is the measure of the size of the mirror.

Principal focus, F: Is the point to wards which reflected rays converge or diverge.

Focal length, F: Is the distance from the pole to the principal focus.



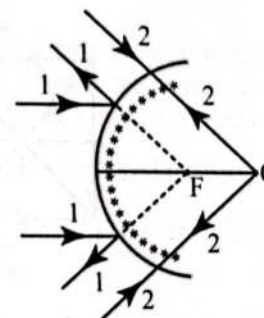
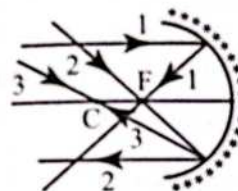
- ☑ The radius of conservator of a curved mirror is equal to twice the focal Length

$$R = 2f$$

$$f = \frac{R}{2}$$

And the three main reflected light rays that are responsible for the formation of an image are the following.

- ☑ An incident ray parallel to the principal axis passes through the principal focus after reflection in concave mirror and appears to come from the principal focus in convex mirror
- ☑ An incident ray moving through the centre of curvature come back gain through the centre of curvature after reflection .
- ☑ An incident ray through the principal focus moves parallel to the principal axis after reflection.

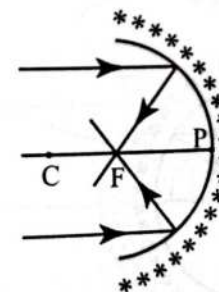


The intersection of two or more of the above reflected rays indicate the position of the image.

Now, let's examine the nature of the image formed by concave and convex mirrors.

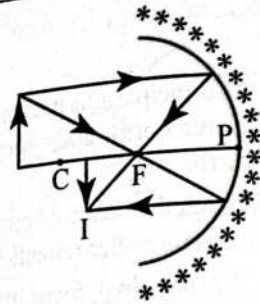
A) Image formed by concave or converging mirror object position Ray Diagram Nature of Image

At Infinity

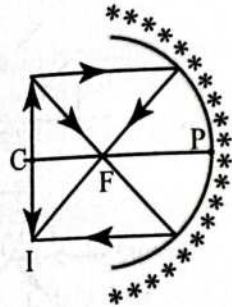


An F Diminished
Real Inverted

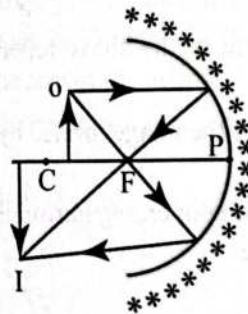
Be Yond C

Between C and F
Diminished Real
Inverted

At C

At C Same size
Real Inverted

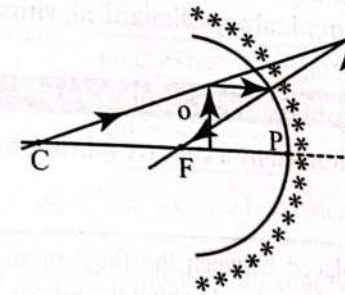
Between C and F

Be yond C
Enlarged Real
Inverted

At F

At Infinity
Enlarged Real
Inverted

Between F and P

Behind the Mirror
Enlarged virtual
Erect

✓ Depending on the location of the object from the mirror, the image formed by concave mirror can be in front of the mirror, behind the mirror, same size, diminished, enlarged, real, virtual, inverted or erect.

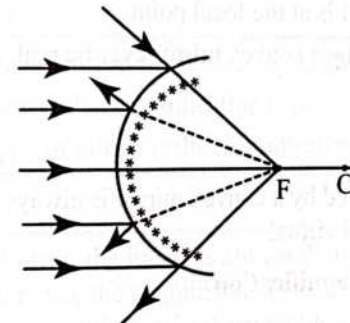
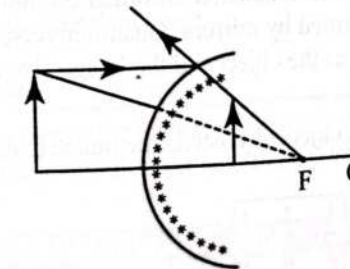
B) Image formed by a convex or diverging mirror object position

Object
position

Ray Diagram

Nature of Image

At Infinity

At F Behind
Mirror
Diminished Virtual
ErectBetween
Infinity and
poleBetween P and
F Behind Mirror
Diminished Virtual
Erect

- ✓ For any position of the object from the mirror, the nature of the image formed by convex mirror is always diminished, virtual, erect and behind the mirror.

Illustrative Examples

35. When will the image formed by a concave mirror become, virtual?

Explanation

When the object is placed between the focal point and the pole, the image is virtual, erect, enlarged and behind the mirror.

36. Can the image formed by a concave mirror ever be

- A) Same size as the object
B) Formed at infinity

Explanation

- A) Yes, when the object is placed at the centre of curvature, the image size is equal to the object size
B) Yes, when the object is at the focal point

37. Can the image formed by a convex mirror ever be real, inverted and enlarged?

Explanation

Never! The image formed by a convex mirror is always erect, diminished and virtual.

Mirror Equation and Magnification

The ray diagrams only give us qualitative information about the location and nature of the image formed by mirrors. Quantitatively, the object and the image distances as well as the object and the image sizes are determined using the mirror equation.

The relationship among the object distance, U , the image distance, V and the focal length, f is given by;

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

And, the size of the image is determined using the magnification equation

of the mirror:

$$\text{Magnification} = \frac{\text{Image size}}{\text{object size}} = - \frac{\text{Image distance}}{\text{object distance}}$$

$$m = \frac{h_i}{h_o} = - \frac{v}{u}$$

To use the mirror equation, we need to stick to the following sign conventions

- ✓ Focal length, f is taken as positive for concave mirror and as negative for convex mirror
- ✓ Image distance V is taken as positive for real image and as negative for virtual image
- ✓ Magnification, m is taken as positive for erect image and as negative for inverted image.

Illustrative Examples

38. For which types of mirror is the magnification always become one?

Explanation

In a flat or plane mirror, the image size is always equal to the object size and hence, the magnification is one.

39. For which type of mirror is the magnification always less than one?

Explanation

In a convex mirror, the image is always diminished, that is smaller than the object. Hence the magnification is always less than one.

40. For which type of mirror will the magnification be equal to one, less than one or greater than one?

Explanation

In a concave mirror, the image may be same size, diminished or enlarged and hence the magnification can be one, less than one or greater than one.

Illustrative Examples

41. What is the focal length of a curved mirror of radius of curvature 20 cm?

Solution

$$f = \frac{R}{2} = \frac{20}{2} \quad f = 10\text{cm}$$

42. A curved mirror of focal length 20 cm forms an erect image of size five times the object size. Where is the image location?

Solution:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$m = \frac{-v}{u} \Rightarrow -5u = v$$

$$\frac{1}{20} = \left(\frac{-v}{5}\right) + \frac{1}{v}$$

$$v = -80\text{cm virtual image}$$

43. A 20cm pencil is placed 6cm in front of a concave mirror of radius of curvature 10cm. Determine

- A) The image distance
B) The image size
C) Magnification of the mirror

Solution

$$\text{A) } \frac{1}{f} = \frac{1}{u} + \frac{1}{v}, f = \frac{R}{2} = \frac{10}{2} = 5\text{cm}$$

$$\frac{1}{5} = \frac{1}{6} + \frac{1}{v}, \frac{1}{v} = \frac{1}{5} - \frac{1}{6} = \frac{6-5}{30} = \frac{1}{30}$$

$$V = 30$$

$$\text{B) } \frac{h_i}{h_o} = \frac{v}{u}$$

$$\frac{h_i}{20} = \frac{-30}{6} = h_i = -100\text{cm, inverted image}$$

$$\text{C) } m = \frac{h_i}{h_o} = \frac{100}{20} = 5$$

44. A pencil of 8cm tall is placed 12cm in front of a converging mirror of

a converging mirror of magnification 4 Determine

- A) The image size
B) The image distance, and
C) The focal length

Solution

$$\text{A) } m = \frac{h_i}{h_o}$$

$$4 = \frac{h_i}{h_o} \Rightarrow h_i = 4(h_o) = 4(8)$$

$$h_i = 32\text{cm}$$

$$\text{B) } m = \frac{-v}{u}$$

$$4 = \frac{-v}{12}$$

$$v = -48\text{cm, virtual image}$$

$$\text{C) } m = \frac{-v}{u}$$

$$4 = \frac{-v}{12} \quad v = -48\text{cm, virtual image}$$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}, m = \frac{-v}{u}$$

$$\text{Substitute } V = -4u = -4(12)$$

$$v = -48\text{cm}$$

45. When a body is placed in front of a concave mirror of focal length 20cm, and image is formed 30cm away. Determine

- A) distance of the object B) nature of the image

Solution

$$A) \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$$

$$\frac{1}{u} = \frac{1}{20} - \frac{1}{30} = \frac{1}{60}$$

$$u = 60\text{cm}$$

B) Real image, because the image distance is positive.

46. When a body is placed 30cm in front of a diverging mirror, a virtual image is formed 10 cm behind the mirror. What is the focal length of the mirror?

Solution:

$$\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$$

$$\frac{1}{f} = \frac{1}{30} - \frac{1}{10}$$

47. If a pen is placed 10cm in front of a convex mirror of focal length 20cm. Then, find the,

- A) image distance
B) magnification of the mirror
C) nature of the image

Solution

$$A) \frac{1}{f} = \frac{1}{u} - \frac{1}{v}$$

$$\frac{-1}{20} = \frac{1}{10} - \frac{1}{v}$$

$$\frac{1}{v} = -\frac{1}{20} - \frac{1}{10} = \frac{-3}{20}$$

$$v = -6.7\text{cm, virtual image}$$

$$B) m = \frac{h_i}{h_o} = \frac{-v}{u} = -\left(\frac{-6.7}{10}\right) = 0.67$$

C) The image is virtual and diminished. since the magnification is less than one and the image distance is negative.

48. What is the focal length and the type of the mirror if an image is formed 10cm from the mirror when an object is placed 30cm in front of it?

49. In a plane mirror, an object is 0.5m in front of the mirror. What will be the distance between the object and image?

- A) 0.5m B) 0.25m C) 1m D) 0.75m

$$\text{Hint: } S = u + v = 0.5 + 0.5$$

$$S = 1\text{m}$$

Answer: C

50. A person standing in front of a mirror finds his image larger than himself. The mirror must be?

- A) Plane C) Concave
B) Convex D) There is no such mirror

Hint: concave mirror forms a various images depending on the object distance.

Answer: C

51. Convex mirror always forms an image that is

- A) Real and inverted C) Virtual and erect
B) Virtual and inverted D) Real and enlarged

Hint: Image of convex mirror is always virtual, erect and diminished.

Answer: C

52. To get three images of an object, one should have plane mirrors at an angle of

- A) 30° B) 60° C) 90° D) 120°

$$\text{Hint: } n = \frac{360^\circ}{\theta} - 1 \Rightarrow \theta = \frac{360^\circ}{n+1} = \frac{360^\circ}{3+1} = 90^\circ$$

Answer: C

53. A object of size 4cm is kept in front of convex mirror at the focal point.

The image size is?

- A) 2cm B) 8cm C) 6cm D) 4cm

Hint: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, $u = f$

$$-\frac{1}{f} = \frac{1}{f} + \frac{1}{v} \Rightarrow v = \frac{f}{2}$$

$$-m = \frac{h_i}{h_o} = \frac{-v}{u} \Rightarrow h_i = \frac{h_o}{2} = \frac{4}{2}$$

$$h_i = 2\text{cm}$$

Answer: A

54. A mirror of focal length 18cm forms a virtual image of magnification $\frac{1}{3}$. What is the object distance?

- A) 18cm B) 48cm C) 36cm D) Infinity

Hint: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, $m = \frac{v}{u} = \frac{1}{3} \Rightarrow v = \frac{u}{3}$

$$-\frac{1}{18} = \frac{1}{u} - \frac{3}{u} \Rightarrow u = 36\text{cm}$$

Answer: B

55. A concave mirror of focal length f forms an image of the same size as the object. The object distance is?

- A) f B) $2f$ C) $f/2$ D) $4f$

Hint: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, $m = \frac{v}{u} = 1 \Rightarrow v = u$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{u} = \frac{2}{u} \Rightarrow u = 2f$$

Answer: B

56. A concave mirror has a radius of curvature of 1m. Light from a distant star is incident on the mirror. The image of the star is at

- A) 0.5m B) 1m C) 2m D) 0.25m

Hint: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, $u = \infty$

$$\frac{1}{f} = \frac{1}{\infty} + \frac{1}{v}, f = \frac{R}{2} = \frac{1}{2} = 0.5\text{m}$$

$$\frac{1}{0.5} = 0 + \frac{1}{v} \Rightarrow v = 0.5\text{m}$$

Answer: A

57. A convex mirror forms an image one-fourth the size of the object. If the object is 0.5m from the mirror, the focal length of the mirror is

- A) 0.17m B) 0.4m C) 1.5m D) 0.5m

Hint: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, $u = 0.5\text{m}$

$$m = \frac{-v}{u} = \frac{h_i}{h_o} = \frac{1}{4} \Rightarrow v = \frac{-u}{4}$$

$$\frac{1}{f} = \frac{1}{u} - \frac{4}{u} = \frac{3}{u}$$

$$f = \frac{u}{3} = \frac{0.5}{3} = 0.17\text{m}$$

Answer: A

58. The refractive index of diamond is 2. What is the speed of light through it?

- A) $3 \times 10^8 \text{ m/s}$ C) $2 \times 10^8 \text{ m/s}$
B) $1.5 \times 10^8 \text{ m/s}$ D) $1 \times 10^8 \text{ m/s}$

Hint: $\frac{n_2}{n_1} = \frac{v_1}{v_2} \Rightarrow v_2 = \left(\frac{n_1}{n_2}\right) v_1$

$$v_2 = \left(\frac{1}{2}\right) (3 \times 10^8) = 1.5 \times 10^8 \text{ m/s}$$

Answer: B

59. The critical angle for medium is 45° . What is its refractive index?

- A) $\frac{\sqrt{3}}{2}$ B) $\frac{2}{\sqrt{3}}$ C) $\sqrt{2}$ D) $\frac{1}{\sqrt{2}}$

Hint: $\frac{\sin i}{\sin r} = \frac{n_2}{n_1} \Rightarrow \frac{\sin 45^\circ}{\sin 90^\circ} = \frac{1}{n_1}$

$$\frac{1}{\sqrt{2}} = \frac{1}{n_1}$$

$$n_1 = \sqrt{2}$$

Answer: C

60. It is possible to observe total internal reflection when a ray travels from
 A) Air in to water
 B) Air in to glass
 C) Water in to glass
 D) Glass in to water
Hint: Total internal reflection occurs when light approaches a lighter medium

Answer: D

61. As an object gets closer to the focal point of a convex lens, its image
 A) Be come smaller
 B) Remains constant
 C) Gets farther from the lens
 D) Gets closer to the lens
Hint: When the object is at the focal point, the image is at infinity

Answer: C

62. The image formed by a lens is always virtual and diminished. The lens is
 A) Convex
 B) Concave
 C) Plane
 D) No such lens
Hint: Concave lens forms virtual, erect and diminished image

Answer: B

63. At what distance from a concave lens of 20cm focal length and half the object size is formed?
 A) 20cm
 B) 10cm
 C) 30cm
 D) 60cm

Hint: $\frac{h_i}{h_o} = \frac{v}{u} \Rightarrow \frac{1}{2} = \frac{v}{u} \Rightarrow v = \frac{u}{2}$
 $\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{20} = \frac{1}{\frac{u}{2}} + \frac{1}{u}$
 $u = 20\text{cm}$

Answer: C

64. Refraction of light wave results from a difference in
 A) Frequency
 B) Amplitude
 C) Speed
 D) Unknown variable
Hint: difference in refractive index causes refraction.

Answer: C

65. The colour of an object is the same as the light that is
 A) Reflected
 B) Refracted

C) Diffracted

D) Interfered

Hint: We see objects when light is reflected from them.

Answer: A

66. All of the waves listed are electromagnetic except
 A) Sound wave
 B) Radio wave
 C) X - ray
 D) Light wave
Hint: Sound wave is mechanical wave

Answer: A

67. Light has a wavelength of 500nm in air and 400nm in a material. What is the index of refraction of the material?
 A) 0.65
 B) 0.85
 C) 1.5
 D) 1.25

Hint: $\frac{n_2}{n_1} = \frac{\lambda_1}{\lambda_2}$

$$n_2 = \frac{500}{400} = 1.25$$

Answer: D

68. Light refracts when traveling from air into glass because light
 A) Travels at the same speed in air and in glass
 B) Has greater frequency in air than in glass
 C) Has greater frequency in glass than in air
 D) Travels slower in glass than in air

Hint: $\frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

Answer: D

69. An object 15cm high is placed 10cm from a converging lens and its image is formed 25cm from the lens. What is the size of the image?
 A) 25cm
 B) 15cm
 C) 30.5 cm
 D) 37.5cm

Hint: $m = \frac{h_i}{h_o} = \frac{-v}{u}$

$$\Rightarrow h_i = h_o \left(\frac{v}{u} \right) = 15 \left(\frac{25}{10} \right)$$

$$h_i = 37.5\text{cm}$$

Answer: D

70. A convex lens of focal length $\frac{1}{3}$ m forms an image twice in size the

object. What is the object distance?

- A) 0.5m B) 0.3m C) 0.2m D) 0.8m

Hint: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{hi}{ho} = \frac{v}{u} \Rightarrow v = 2u$$

$$3 = \frac{1}{u} + \frac{1}{2u} = \frac{3}{2u}$$

$$u = 0.5m$$

Answer: A

Solution:

$$\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$$

$$\frac{1}{f} = \frac{1}{30} - \frac{1}{10}$$

$$\frac{1}{f} = -\frac{1}{15}$$

$$f = -15cm, \text{ convex mirror}$$

Lenses

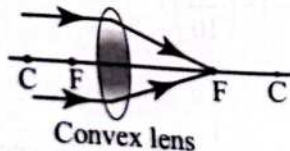
A curved transparent material that is smooth and regularly shaped so that when light strikes it the light refracts through it is called *lens*

Lens: Is a transparent material bound by two surfaces of which one or both of them are spherical.

The most common types of lenses are two. convex and concave.

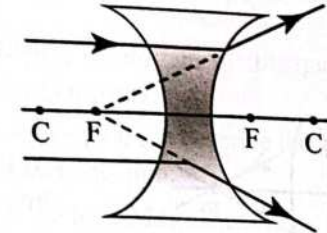
Convex Lens: Is a lens bulging outward, and is thicker at the middle than at the edges.

This lens causes light rays to come together and for this reason, convex lens is also called converging lens



Concave Lens: Is a lens curved inwards, and is thicker at the edges than at the middle.

This lens causes refracted light rays to spread out, and for this reason, concave lens is also called *diverging lens*.



Concave Lens

☑ Unlike mirrors, lenses have two focal points and form images by refraction of light.

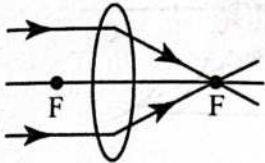
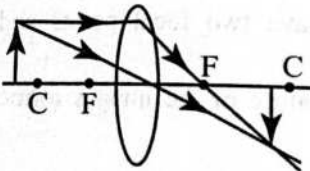
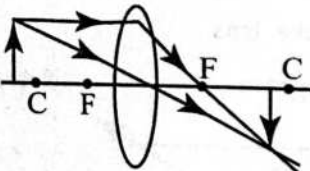
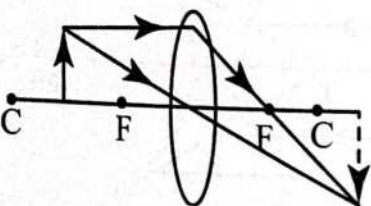
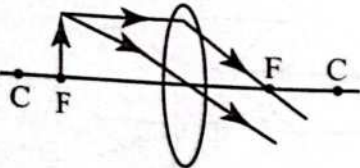
Now, let us examine the nature of the images formed by concave and convex lenses.

A) Image formed by concave lens

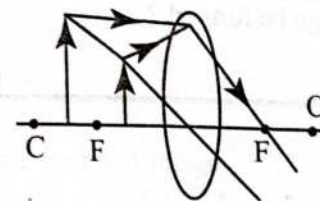
Object position	Ray Diagram	Nature of Image
At Infinity		At F diminished Virtual Erect
Between Infinity and pole		Between P × F Diminished virtual Erect

B) Image formed by a convex Lens

Unlike the concave lens that always forms a virtual, erect, and diminished image regardless of the object position, convex lens forms real, virtual, erect, inverted, diminished the object from the mirror

Object position	Ray Diagram	Nature of Image
At Infinity		At F Diminished Real Inverted
Be Yond C		Between C and F Diminished Real Inverted
At C		At C same size Real Inverted
Between C and F		Be Yond C Enlarged Real Inverted
At F		At Infinity, Enlarged

Between F and P



Enlarged, virtual

The ray diagrams give us only the qualitative aspect of the image natures formed by the corved mirrors.

Quantitatively however, we can describe the size and distance of the image formed using the lens equation.

The Lens Equation and Magnification

The relationship among the image distance (V) object distance (u) and the focal length (f) is given by the lens equation as follows

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

And, magnification of the lens is obtained by :

$$\text{Magnification} = \frac{\text{Image size}}{\text{object size}} = \frac{\text{Image distance}}{\text{object distance}}$$

$$m = \frac{h_i}{h_o} = \frac{-v}{u}$$

To use the lens and the magnification equations, appropriately we need to stick to the following sign conventions.

Sign conventions

- ☑ Focal length, f is taken as positive for convex lens and as negative for concave lens
- ☑ Image distance, v is taken as positive for real image and as negative for virtual image
- ☑ Magnification, m is taken as positive for erect image and as negative for inverted image

Illustrative Examples

71. If an object is placed 24 cm in front of a concave lens of focal length

12cm, where will the image be formed?

Solution:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{12} - \frac{1}{24} = -\frac{1}{8}$$

$v = -8\text{cm}$, virtual image

72. If a body is placed 40 cm in front of a converging lens of focal length 30cm, how far from the lens will the image be formed?

Solution

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{30} - \frac{1}{40} = \frac{1}{120}$$

$v = 120$, real image

73. A 5cm nail is placed 10cm from a convex lens of focal length 15 cm. Determine the;

A) Image distance

B) Image size

C) Nature of the image

D) Magnification of the lens

Solution

$$A) \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{15} - \frac{1}{10} = -\frac{1}{30}$$

$v = 30\text{cm}$ virtual image

$$B) \frac{h_i}{h_o} = \frac{-v}{u}$$

$$\frac{h_i}{5} = \frac{-30}{10}$$

$h_i = -15\text{ cm}$, inverted image

C) The image is virtual, inverted and enlarged

$$D) m = \frac{h_i}{h_o} = \frac{15}{5} \quad m = 3$$

74. When a 10 cm tall pencil is placed 20 cm in front of a convex lens, an image is formed 20 cm from the lens. Determine

A) Focal length of the lens

B) Size of the image

Solution

$$A) \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{20} + \frac{1}{30} = \frac{2}{10} = \frac{1}{5}$$

$f = 10\text{cm}$

$$B) \frac{h_i}{h_o} = \frac{-v}{u}$$

$$\frac{h_i}{10} = \frac{-20}{20} \quad h_i = -10\text{cm, inverted image}$$

75. A body placed in front of a concave lens of magnification 0.2 forms an image 5cm from the lens. Determine the

A) Object distance

B) Focal length of the lens

Solution

$$A) m = \frac{v}{u} \Rightarrow 0.2 = \frac{5}{u}, u = 25\text{cm}$$

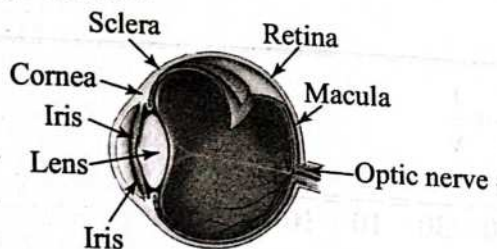
$$B) \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{25} - \frac{1}{5} \Rightarrow f = 6.25 \text{ cm}$$

11.6 The Human Eye and Optical Instruments

The Human Eye

The eye may a converging lens and it is like a camera light enters the eye through a thin membrane called the cornea where most refraction occurs and reaches the lens. The lens forwards the rays to the retina where an inverted image is formed.



Behind the cornea, there is the Iris, which is a dark muscular diaphragm that controls the size of the pupil. The pupil is a structure that regulates and controls the amount of light entering the eye.

The retina is a delicate membrane with many light sensitive cells. The light sensitive cells get activated when illuminated and generate electrical signals which are then sent to the brain via the optic nerves and get interpreted.

- ☑ The eye consists of a convex lens made of living tissues that focuses images on the retina where the optic nerve transfers the message to the brain where the message gets interpretation.

Power of Accommodation

The eye lens is made of fibrous, jelly like living tissues and its curvature is adjusted by the ciliary muscles. When these muscles are relaxed, the lens becomes thin and its focal length increases and enables us to see distant objects clearly. When the muscles contract, the lens becomes thick and its

focal length decreases. and enables us to see near by objects clearly.

To see an object comfortably and distinctly without strain and be long blurred it must be about 25 cm from the eye.

- ☑ For the normal human eye, the near point is about 25 cm and the far point is infinity.

The minimum distance at which objects can be seen most distinctly without strain is called the least distance of distinct vision or the near point of the eye and is equal to 25 cm. And, the farthest point up to which the eye can see objects clearly is called the far point of the eye and is equal to infinity.

For many reasons, the eye may be defected and malfunction.

Defects of vision and Their corrections

The eye may lose its power of accommodation and the vision becomes blurred due to the refractive defects of the eye.

The following are the main defects of the eye and their corrections.

Myopia - Near sightedness

A short-sighted person can see nearby objects clearly but cannot see distant objects distinctly.

In a myopic eye, the image of a distant object is formed in front of the retina, not on the retina. The defect may arise due to excessive curvature of the eye lens or elongation of the eyeball.

- ☑ This defect can be corrected by using spectacles with a concave lens.

Hypermetropia - far Sightedness

A long-sighted person can see distant objects clearly but cannot see nearby objects distinctly.

In a hypermetropic eye, the image of a nearby object is formed behind the retina, not on the retina. The defect may arise due to either too long focal length of the eye lens or too small eyeball size.

- ☑ This defect can be corrected by using spectacles with a convex lens.

Presbyopia - Old Sight

The eye loses its power of accommodation as we get aged. At old ages, the near point recedes away.

This defect arises due to the weakening of the ciliary muscles and lack of

flexibility of the eye lens as we get aged.

- ☑ This defect can be corrected using spectacles with bi-focal lenses. A concave lens, to facilitate near vision.

Astigmatism

This defect is caused when the eye has two different focal length,

- ☑ It is corrected with a pair of spectacles fitted with cylindrical lenses.

Illustrative Examples

Match the items in column A with those in column B

A

76. Myopia
77. Hypermedia
78. presbyopia
79. Astigmatism

B

- A) long sighted
B) short sighted
C) Age factor
D) same focal length
E) Different focal length

Answers

53. B

55. C

54. A

56. E

Optical Instruments

So many optical devices are made using the reflective and refractive natures of mirrors, lenses and prisms.

Microscope, telescope, binocular, camera, eye-glasses are some examples of optical instruments

Microscope

It is used to see very small objects; such as bacteria, virus --- etc.

Microscope has an objective lens of convex lens and an eyepiece lens of convex lens both are designed to form an enlarged image.



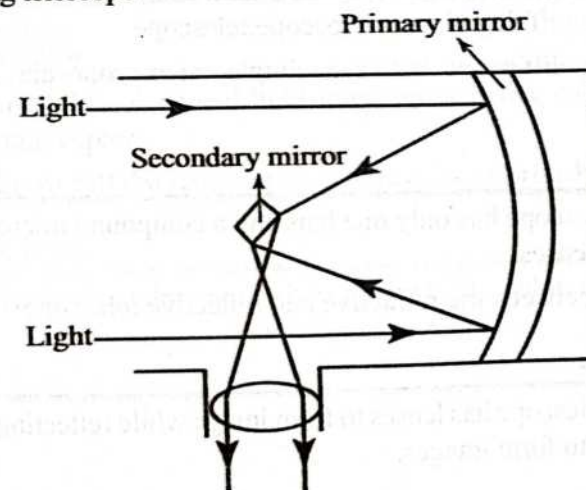
Telescope

It is used to see objects that are very far away such as the stars, planets and the space

The refracting telescope uses two convex lenses to form an image of a distant object. It has an objective and eye piece lenses.



The reflecting telescope has a concave mirror and has much larger size than the refracting telescope



Illustrative Examples

80. What is the power of accommodation ?

Explanation

It is the ability of the eye lens to adjust its focal length

81. What is the corrective lens for a myopia ?

Explanation

A concave lens to diverge the light rays

82. What is the near point and the far point of the human eye for normal vision ?

Explanation

The near point is about 25cm and the far point is infinity.

83. A student has difficulty reading the blackboard when sitting at the last seat. What eye defect he has and how can it be corrected ?

Explanation

Myopia, can be corrected by a concave lens.

84. List some optical instruments

Explanation

Camera, magnifying glass, microscope, telescope

85. What is the difference between simple microscope and compound microscope ?

Explanation

Simple microscope has only one lens and a compound microscope has at least two lenses.

86. Distinguish between the refractive and reflective telescope

Explanation

Refracting telescope has lenses to form image while reflecting telescope uses mirrors to form images.

87. What type of telescope is there in Entoto observatory centre ?

Explanation

It is a reflecting telescope

11.7 Primary Colors of light and Human Vision

The retina in the human eye where image is formed is full of millions of light receptive cells called cones which are sensitive to colors and rods which are sensitive to light intensity.

When the cones and rods detect light, they send signal to the brain for interpretation. The brain, name the type of object and its colour. so you see, we are able to see an object when light from the object enters the eye and strikes these photoreceptor cells.

The cones are of three sets. one set sensitive to red light, another set sensitive to green light and a third set sensitive to blue light. These colours, red, green and blue are fundamental to the human vision are called **primary colours**.

✓ Red, green and blue are primary colours. All other colours of the visible light spectrum can be produced by adding these three colours. And, if equal amount of the primary colours are added, white light is produced.

Illustrative Examples

88. What are the cones and rods cells found on the retina sensitive

Explanation

They are light colour and light intensity sensitive cells usually called the photoreceptor.

89. Why do we call the red, green and blue colours primary

Explanation

Because, their combination gives all the other colours of the spectrum.

11.8 Colour Addition of Light

The red, green and blue colours are often described as the primary additive colours since their addition gives all the other colours. Appropriate combination of the primary colours, red, green and blue gives the secondary colours, cyan, magenta and yellow.

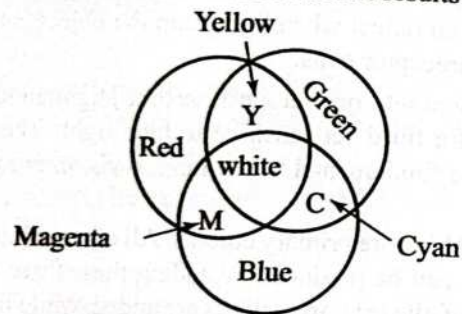
Red + Green = Yellow

Red + Blue = Magenta

Blue + Green = Cyan

☑ Yellow, Magenta and Cyan are called secondary colours of light

Remember: when added in equal proportions, red, green and blue gave white light, and the absence of all three colours results in Black !



Illustrative Examples

90. What colors will you get if you add proportionally;

- A) Red and blue B) Red and green C) Green and blue

Explanation

A) Red + Blue = Magenta

B) Red + Green = Yellow

C) Green + Blue = Cyan

91. What applications did color addition has ?

Explanation

The principles of color addition have important applications in color television, color computer monitors and on stage light systems, digital projector --- etc.

Match the items in column A with those in column B

A

92. Yellow

93. Magenta

94. Cyan

B

A) Red + Blue

B) Green + Blue

C) Red + Green

D) Yellow + Green

Answers

92. C

93. B

94. A

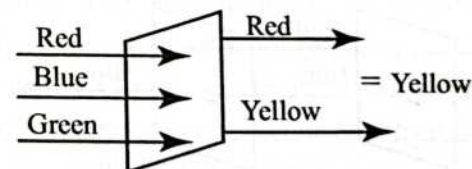
11.9 Colour Subtraction of Light Using Filters

The colours that are absorbed are subtracted from the reflected light. Colour subtraction is achieved using pigments or color filters.

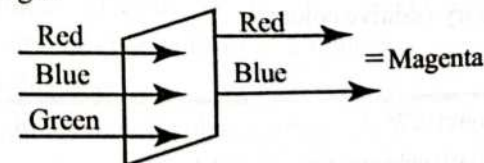
☑ Pigments are substances which give an object its color by absorbing certain frequencies of light and reflecting other frequencies. For example, a red pigment absorbed all colours of light except red which it reflects. color to pass through by absorbing all the rest. for example, when white light passes through a red filter, only red light passes and all the rest are absorbed.

The Following shows color subtraction using filters or pigments.

i. Yellow filter or pigment absorbs Blue and transmits Red and Green and gives yellow Light

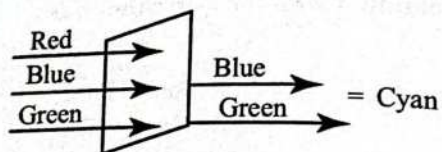


ii. Magenta filter absorbs Green and transmits Red and Blue and gives magenta light

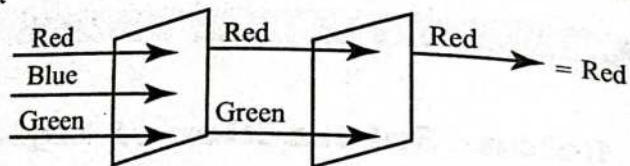


iii. Cyan filter absorbs Red and transmits Blue and Green and gives cyan

light

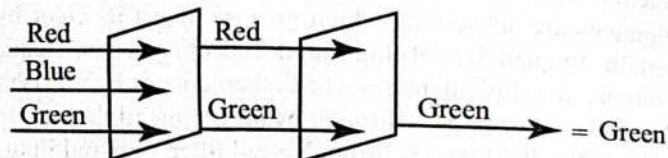


- iv. Yellow filter absorbs Blue and magenta filter absorbs Green and gives Red light



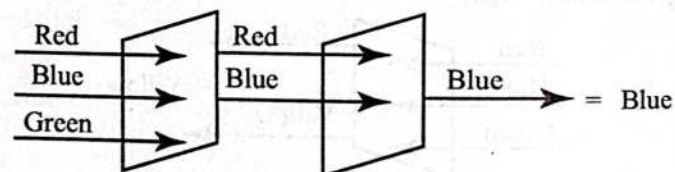
Yellow + Magenta Filters

- v. Yellow filter absorbs Blue and cyan filter absorbs Red and gives Green light



Yellow + Cyan Filters

- vi. Magenta filter absorbs Green and cyan filter absorbs Red and gives Blue light



Magenta + Cyan Filters

95. What are the primary additive colors ?

Explanation

Red, Blue and Green

What are the primary subtractive colors ?

Explanation

Yellow, Magenta and Cyan

96. What are the complimentary colors ?

Explanation

Complimentary colors are the colors that are absorbed by the subtractive primaries. Therefore, cyan's compliment is Red, magenta's compliment is Green and Yellow's compliment is Blue.

Match the items in column A with those in column B

A

97. Green

98. Red

99. Blue

B

A) Cyan - Blue

B) Magenta - Red

C) Yellow - Green

D) Yellow + Blue

Answers

97. A

98. B

99. C

End of unit Questions and problems

1. Give short answers to the following Questions

- What is the speed of light in vacuum ?
- Why do we protect ourselves from UV light exposure ?
- Give advantage and disadvantage of x - rays
- List the electromagnetic spectrum in order of increasing wavelength ?
- Mirrors form image from reflection of light and lenses form image via refraction of light. True or False ?
- Name the type of mirror used in the following situation
 - Headlights of a car
 - Side or rear - view mirror of a vehicle
 - Solar furnace
- The magnification of a plane mirror is 1. What does this mean ?
- Compare and contrast primary light colours and primary pigment colour.
- Determine the colours that are reflected from an object that appears black.

10. What colour do the following Shirts appear to the human eye when the lights in a room are turned off.
 A) Red
 B) Blue
11. If the cover of a book appears to have a magenta colour, then what colours of light does it reflect and what colours does it absorb?

II. End Of unit Problems

12. A concave lens of focal length 15 cm forms an image 10cm from the lens. How far is the object placed from the lens?
13. An object is placed at a distance of 10 cm from a convex mirror of focal length 15cm. Find the position and nature of the image.
14. An object 5cm in length is placed at a distance of 20cm in front of a convex mirror of curvature 30cm. Find the position of the image, its nature and size.
15. An object of size 7cm is placed at 27cm in front of a concave mirror of focal length 18cm. Find the size, position and nature of the image.
16. An object 5cm in length is held 25cm away from a converging lens of focal length 10cm. Find the position, size and nature of the image.
17. A convex lens produces a virtual image which is four times larger than the object. The image is 15cm from the lens. What is the focal length of the lens?

Answers to End of unit Questions

- $C = 3 \times 10^8 \text{ m/s}$
- Because, it cause sun burn and cancel
- It helps to diagnose to moues with out surgery but over dose of it causes cancer.
- γ - ray, x- ray, UV light, visible light, infrared, microwave and radio wave
- Yes It is True statement
- a) concave mirror b) convex mirror c) concave mirror
- It means, the image size is equal to the object size.
- The primary colours of light are red, blue and green, and the primary colours of pigment are red, blue and yellow
- An object that appears black absorbs all colours and no colour is

reflected from it

10. No colour can be seen for both shirts
11. Magenta is a combination of red and blue. Hence, the cover of the book must be reflecting blue and red lights and absorbing green.

Solution to the End of unit problems

$$12. \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{-1}{15} + \frac{1}{10} = \frac{1}{30}$$

$u = 30\text{cm}$, one option.

Object should be placed between infinity and lens centre

$$13. \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{-1}{15} - \frac{1}{10} = -\frac{1}{6}$$

$v = -6\text{cm}$, virtual, erect, diminished

$$14. \frac{1}{f} = \frac{1}{u} + \frac{1}{v}, f = \frac{R}{2} = \frac{30}{2} = 15\text{cm}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{-1}{15} - \frac{1}{20} = -8.6$$

$v = 8.6\text{cm}$, virtual, erect, diminished

$$m = \frac{-v}{u} = \frac{h_i}{h_o}$$

$$h_i = \frac{v h_o}{u} = \frac{(8.6)(5)}{20} = 2.14\text{cm}$$

$$15. \quad \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{18} - \frac{1}{27} = -\frac{1}{54}$$

$v = -54\text{cm}$, virtual, erect, enlarged

$$m = \frac{-v}{u} = \frac{54}{27} = 2$$

$$16. \quad \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{25} = \frac{3}{50}$$

$v = \frac{50}{3}\text{cm}$, real, inverted, and diminished

$$m = \frac{-v}{u} = \frac{-\frac{50}{3}}{25} = -0.67$$

$$17. \quad \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$m = \frac{h_i}{h_o} = \frac{-v}{u} = 4$$

$$u = \frac{15}{4}\text{cm}$$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{\frac{15}{4}} - \frac{1}{15} = \frac{3}{15}$$

$$f = 5\text{cm}$$



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